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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/570,023	03/01/2006	Sureshchandra B. Patel		1118

7590 11/24/2008

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CANADA

EXAMINER	
BARNES-BULLOCK, CRYSTAL JOY	
ART UNIT	**PAPER NUMBER**
2121	

MAIL DATE	DELIVERY MODE
11/24/2008	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Office Action Summary	Application No. 10/570,023	Applicant(s) PATEL, SURESHCHANDRA B.
	Examiner Crystal J. Barnes Bullock	Art Unit 2121

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *01 March 2006*.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-11* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☒ Claim(s) *9-11* is/are allowed.

6)☒ Claim(s) *1-8* is/are rejected.

7)☒ Claim(s) *4* is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☒ The drawing(s) filed on *17 June 2008* is/are: a)☒ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☒ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☒ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☒ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)

2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)

3) ☐ Information Disclosure Statement(s) (PTO/SB/08) Paper No(s)/Mail Date _____.

4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____.

5) ☐ Notice of Informal Patent Application

6) ☐ Other: _____.

DETAILED ACTION

1. The following is an initial Office Action upon examination of the above-identified application on the merits. Claims 1-11 are pending in this application.

Priority

2. Acknowledgment is made of applicant's claim for foreign priority based on an application filed in Canada on 3 September 2002. It is noted, however, that applicant has not filed a certified copy of the 2,400,580 application as required by 35 U.S.C. 119(b).

Information Disclosure Statement

3. The listing of references in the specification is not a proper information disclosure statement. 37 CFR 1.98(b) requires a list of all patents, publications, or other information submitted for consideration by the Office, and MPEP § 609.04(a) states, "the list may not be incorporated into the specification but must be submitted in a separate paper." Therefore, unless the references have been cited by the examiner on form PTO-892, they have not been considered.

Claim Objections

4. Claim 4 is objected to because of the following informalities:

system/method should be system. Appropriate correction is required.

Claim Rejections - 35 USC § 112

5. The following is a quotation of the second paragraph of 35 U.S.C. 112:

> The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

6. Claim 1 is rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

Regarding claim 1, the term "etc." renders the claim(s) indefinite because the claim(s) include(s) elements not actually disclosed (those encompassed by "etc."), thereby rendering the scope of the claim(s) unascertainable. See MPEP § 2173.05(d).

Allowable Subject Matter

7. Claims 9-11 are allowed.

8. Claim 1 would be allowable if rewritten or amended to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action.

9. Claim 2-8 would be allowable if rewritten to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action and to include all of the limitations of the base claim and any intervening claims.

10. The following is a statement of reasons for the indication of allowable subject matter:

As per claim 1, the prior art of record taken alone or in combination fails to teach performing Loadflow computation at said nodes of the power system by a Super Super Decoupled computation in any of the Super Super Decoupled Loadflow methods or any of their hybrid combination or simple variants employing corresponding gain matrices derived from a super decoupled Jacobian matrix for real power with respect to angle and a super decoupled Jacobian matrix for reactive power with respect to voltage, and involving triangular factorization of said gain matrices and computing of discrepancy of real power and reactive power from specified values through such nodes, said computing including introducing

variables representing quotients of the transformed discrepancies from specified values of real and reactive power flowing in through each node divided by voltage, or square of the voltage in case of transformed real power mismatches in methods employing (1.theta., 1V) iteration scheme, on each node, and using such variables to calculate values of angle and voltage for said transformed discrepancies from specified values of real and reactive power flowing in through each node, by using triangular factorization of said gain matrices for real and reactive power and restricting nodal transformation angle to maximum -48 degrees, applied to complex power injection in computing said transformed discrepancies from specified values of real and reactive power flowing in through each node.

As per claim 9, the prior art of record taken alone or in combination fails to teach controlling the operation of the excitation element of at least one machine to produce or absorb the amount of reactive power indicated by any of the said Super Super decoupled models with respect to the set of specified parameters.

Conclusion

11. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

The following references are cited to further show the state of the art with respect to electrical power system regulation:

USPN 7,096,175 B2 to Rehtanz et al.

USPN 7,096,165 B2 to Pantenburg et al.

USPN 6,754,597 B2 to Bertsch et al.

USPN 6,690,175 B2 to Pinzon et al.

USPN 6,313,752 B1 to Corrigan et al.

USPN 5,610,834 to Schlueter

USPN 5,566,085 to Marceau et al.

USPN 5,305,174 to Morita et al.

USPN 5,081,591 to Hanway et al.

USPN 4,974,140 to Iba et al.

USPN 4,868,410 to Nakamura

US Pub. No. 2007/0203658 A1 to Patel

WO 2004/023622 A2 to PATEL

CA 2107388 A to PATEL

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Crystal J. Barnes Bullock whose telephone number is 571.272.3679. The examiner can normally be reached on Monday-Friday.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Albert Decady can be reached on 571.272.3819. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/Crystal J. Barnes Bullock/
Primary Examiner, Art Unit 2121
21 November 2008

Notice of References Cited	Application/Control No. 10/570,023	Applicant(s)/Patent Under Reexamination PATEL, SURESHCHANDRA B.	
	Examiner Crystal J. Barnes Bullock	Art Unit 2121	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-7,096,175	08-2006	Rehtanz et al.	703/18
*	B	US-7,096,165	08-2006	Pantenburg et al.	703/1
*	C	US-6,754,597	06-2004	Bertsch et al.	702/57
*	D	US-6,690,175	02-2004	Pinzon et al.	324/525
*	E	US-6,313,752	11-2001	Corrigan et al.	340/657
*	F	US-5,610,834	03-1997	Schlueter, Robert A.	700/293
*	G	US-5,566,085	10-1996	Marceau et al.	700/293
*	H	US-5,305,174	04-1994	Morita et al.	361/63
*	I	US-5,081,591	01-1992	Hanway et al.	323/205
*	J	US-4,974,140	11-1990	Iba et al.	363/74
*	K	US-4,868,410	09-1989	Nakamura, Shizuka	307/20
*	L	US-2007/0203658	08-2007	Patel, Sureshchandra B.	702/060
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N	WO 2004023622 A2	03-2004	World Intellect	PATEL, SURESHCHANDRA	
	O	CA 2107388 A	05-1995	Canada	PATEL S B	
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
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(43) International Publication Date
18 March 2004 (18.03.2004)

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(25) Filing Language: English

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(30) Priority Data:
2,400,580 3 September 2002 (03.09.2002) CA

(71) Applicant and
(72) Inventor: PATEL, Sureshchandra [IN/CA]; 159 Campbell Avenue, Symington Ave & Wallace Avenue, Toronto, Ontario M6P 3V3 (CA).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

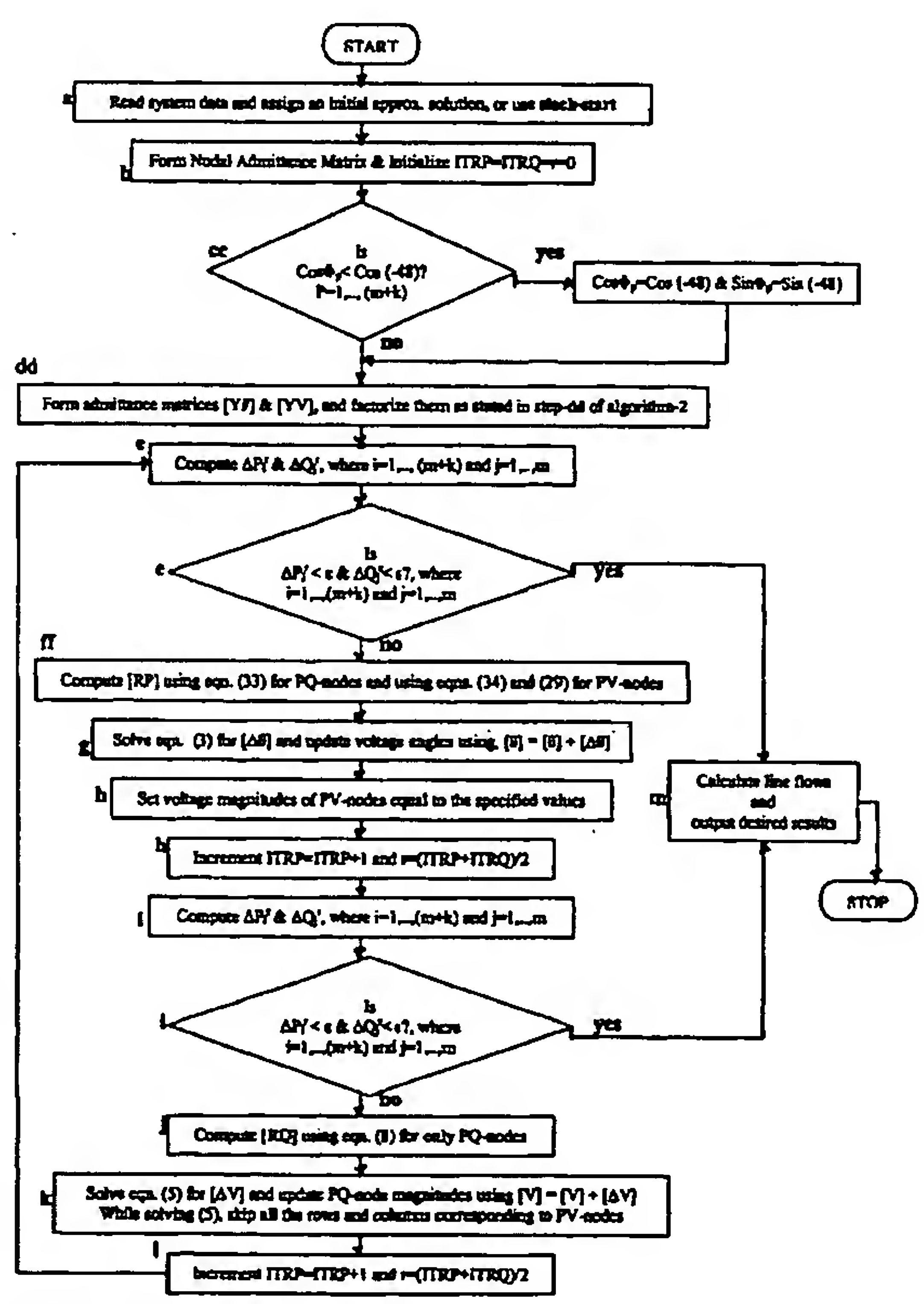
(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for all designations*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*
— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *without international search report and to be republished upon receipt of that report*

[Continued on next page]

(54) Title: SYSTEM OF SUPER SUPER DECOUPLED LOADFLOW COMPUTATION FOR ELECTRICAL POWER SYSTEM



Flow-chart of SSDL-YY solution algorithm-2

(57) Abstract: Load-Flow computations are performed in real-time operation/control and in on-line/off-line studies of electrical power systems. Three Load-Flow computation methods of the present invention are the best versions of many simple variants with almost similar performance. The Super Super Decoupled Loadflow (SSDL-YY) method and its many variants are characterized in limiting rotation angle applied to nodal real and reactive power mismatches to the maximum of -48 degrees instead of -36 degrees, replacing network shunt element $-2b_p\mathrm{Cos}\Phi_p$ by $[2(QSH_p\mathrm{Cos}\Phi_p - PSH_p\mathrm{Sin}\Phi_p)/V_s^2]$ or by $[-b_p\mathrm{Cos}\Phi_p + (QSH_p\mathrm{Cos}\Phi_p - PSH_p\mathrm{Sin}\Phi_p)/V_s^2]$ and using the dividing term V^2 instead of V in the modified nodal real power residues [RP] in the prior art Fast Super Decoupled Loadflow (FSDL) method. The other two Super Super Decoupled Loadflow: BGX' version (SSDL-BGX') and $X'G_{pv}X'$ version (SSDL-$X'G_{pv}X'$) are characterized in the use of simultaneous (1V,1θ) iteration scheme thereby reducing the mismatch computation once compared to two mismatch computations in the prior art method employing successive (1θ,1V) iteration scheme. The invented methods are also characterized in the different definition of gain matrices as detailed in the steps of algorithm-2, algorithm-3 and algorithm-4 of carrying out of the inventions. (steps-cc, -dd, and ff in Fig.2; steps-ccc, -ddd, -fff, -ggg and -hhh in Fig.3; steps-dddd and -ffff in Fig. 4) leading to some speed-up of the invented methods.

WO 2004/023622 A2

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SYSTEM OF SUPER SUPER DECOUPLED LOADFLOW COMPUTATION FOR ELECTRICAL POWER SYSTEM

TECHNICAL FIELD

The present invention relates to methods of loadflow computation in power flow control and voltage control for an electrical power system.

BACKGROUND ART AND MOTIVATION

Utility/industrial power networks are composed of many power plants/generators interconnected through transmission/distribution lines to other loads and motors. Each of these components of the power network is protected against unhealthy (faulty, over/under voltage, over loaded) potentially damaging operating conditions. Such protection is automatic and operates without the consent of power network operator, and takes an unhealthy component out of service disconnecting it from the network. The time domain of operation of the protection is of the order of milliseconds.

The purpose of a utility/industrial power network is to meet the electricity demands of its various consumers 24-hours a day, 7-days a week while maintaining the quality of electricity supply. The quality of electricity supply means the consumer demands be met at specified (say + or - 5% tolerance) voltage and frequency levels without over loaded, under/over voltage operation of any of the power network components. The operation of a power network is different at different times due to changing consumer demands and/or development of any faulty/contingency situation. In other words healthy operating power network is constantly subjected to small or large disturbances. These disturbances could be operator initiated, or initiated by security control functions and various optimization functions such as economic operation, minimization of losses etc., or caused by a fault/contingency incident.

For example, a power network is operating healthy and meeting quality electricity needs of its consumers. A fault occurs on a line or a transformer or a generator which faulty component gets isolated from the rest of the healthy network by virtue of the automatic operation of its protection. Such a disturbance would cause a change in the pattern of power flows in the network, which can cause over loading of one or more of the other components and/or over/under voltage at one or more nodes in the rest of the network. This in turn can isolate one or more other components out of service by virtue of the operation of associated protection, which disturbance can trigger chain reaction disintegrating the power network.

Therefore, the most basic and integral part of all other functions (e.g. optimizations) in power network operation and control is security control. Security control means controlling power flows so that no component of the network is over loaded and controlling voltages such that there is no over voltage or under voltage at any of the nodes in the network following a disturbance small or large. Security control functions (overload alleviation and over/under voltage alleviation) can be realized through one or combination of more controls in the network. These involve control of power flow over tie line connecting other utility network, turbine steam/water input control to control real power generated by each generator, load shedding function curtails load demands of consumers, excitation controls reactive power generated by individual generator which essentially controls generator terminal voltage, transformer taps control connected node voltage, switching in/out in capacitor/reactor banks controls reactive power at the connected node. Such overload and under/over voltage alleviation functions produce control amount changes in step-60 of Fig.5. These control amount changes could be even optimized in case of simulation of all possible imaginable disturbances (outage of a line, loss of generation etc.) for corrective action stored and made readily available for acting upon in case the simulated disturbance actually occurs in the power network. In fact simulation of all possible imaginable disturbances is the modern practice because corrective actions need be taken before the operation of individual protection of unhealthy component.

Control of an electrical power system (Power-flow control, voltage control etc.) is performed according to the process flow diagram of fig.5. The various numbered steps in fig.5 are explained in the following.

Step-10: On-line readings of various real-time power flows, voltages, circuit breaker status (open/close) etc. are obtained

Step-20: A control amount (i.e. change in power injections, voltages etc.) is initially established and proposed

Step-30: Various power flows, voltage magnitudes and angles, reactive power generations by generators and turns ratios of transformers in the power system are determined by performing loadflow computation, which incorporates established/proposed/set control adjustments

Step-40: The results of Loadflow computation of step 30 are evaluated for any over loaded transmission lines and over/under voltages at different nodes in the power system

Step-50: If the system state is good (no over loaded lines and no over/under voltages), the process branches to step 70, otherwise to 60

Step-60: Changes the control amount initially set in step-20 or later set in the previous process cycle step-60 and returns to step-30

Step-70: Actually implements the control amount correction to obtain secure/optimum/correct/acceptable operation of power system

It is obvious that Loadflow computation is performed many times in real-time operation and control environment and, therefore, **high-speed (efficient) Loadflow computation is necessary** to provide corrective control in the changing power system conditions including an outage or failure. Moreover, the **loadflow computations must be highly reliable to yield converged solution under wide range of system operating conditions and network parameters**. Failure to yield converged loaflow solution creates blind spot as to what exactly could be happening in the network leading to potentially damaging operational and control decisions/actions in capital-intensive power utilities.

The embodiment of the present invention, the most efficient and reliable loadflow computations, as described in the above steps and in Fig.5 is very general and elaborate. The control of voltage magnitude within reactive power generation capabilities of electrical machines (generators, synchronous motors, capacitor/inductor banks) and within operating ranges of transformer taps is normally integral part of Loadflow computation as described in "LTC Transformers and MVAR violations in the Fast Decoupled Loadflow, IEEE PAS-101, No.9, PP. 3328-3332." If under/over voltage still exists in the results of Loadflow computations, other control actions are taken in step-60 in the above and in Fig.5. For example, under voltage can be alleviated by shedding some of the load connected.

However, the simplest embodiment of the efficient and reliable system and method of loadflow computations is where only voltage magnitudes are controlled by controlling reactive power generation of generators and motors, switching in/out in capacitor/inductor banks and transformer taps. Of course, such control is possible only within reactive power capabilities of machines and capacitor/reactor banks, and within operating ranges of transformer taps. This is the case of a network in which the real power assignments have already been fixed and in which steps-50 and -60 in the above and in Fig.5 are absent. Once loadflow computations are finished, the Loadflow solution includes indications of reactive power generation at generator nodes and at the nodes of the capacitor/inductor banks, and indications of transformer tap settings. Based on the known reactive power capability characteristics of the individual machines, the determined reactive power values are used to adjust the excitation current to each machine, or at least each machine presently under reactive power, or VAR, control, to establish the desired reactive power set points. The transformer taps are set in accordance with the tap setting indications produced by the Loadflow computation system.

This procedure can be employed either on-line or off-line. In off-line operation, the user can simulate and experiment with various sets of operating conditions and determine reactive power generation and transformer tap settings requirements. A general-purpose computer can implement the entire system. For on-line operation, the loadflow computation system is provided with data identifying the current real and reactive power assignments

and transformer transformation ratios, the present status of all switches and circuit breakers in the network and machine characteristic curves in steps-10 and -20 in the above and in Fig. 5, and blocks 10, 12, 14, 20, 30, 40, 42, 44, 50, 52 in Fig 6. Based on this information, a model of the system based on gain matrices of any of the invented or prior art Loadflow computation methods provide the values for the corresponding node voltages, reactive power set points for each machine and the transformation ratio and tap changer position for each transformer.

The present invention relates to control of utility/industrial power networks of the types including plurality of power plants/generators and one or more motors/loads, and connected to other external utility. In the utility/industrial systems of this type it is the usual practice to adjust the real and reactive power produced by each generator and each of the other sources (synchronous condensers, capacitor/inductor banks) in order to optimize the real and reactive power generation assignments of the system. Healthy (secure) operation of the network can be shifted to optimized operation through corrective control (disturbance) produced by optimization functions without violation of security constraints. This is referred to as security constrained optimization of operation. Such an optimization is described in the United States Patent Number: 5,081,591 dated Jan. 13, 1992 (Optimizing Reactive Power Distribution in an Industrial Power Network) where the present invention can be embodied by replacing the block nos. 56 and 66 by a block of constant matrices [Yθ] and [YV], and replacing blocks of "Exercise Newton-Raphson Algorithm" by blocks of "Exercise Fast Super Decoupled Algorithm" or "Execise Super Super Decoupled Algorithm" in place of blocks 58 and 68.

DISCLOSURE OF THE INVENTION

This invention relates to steady-state power network computation referred to as Loadflow or Power-Flow. Loadflow computations are performed as a step in real-time operation/control and in on-line/off-line studies of Electrical Power Systems. The present invention involves three-methods. These 3-methods are the best versions of many simple variants with almost similar performance. Simple variants include any possible hybrid

combination of these 3-methods and unsymmetrical definitions of [Yθ] in SSDL-method. **Among these 3-methods, their variants and all other known methods, Super Super Decoupled Loadflow (SSDL-YY) is the simplest, easiest to implement and overall best in performance (reliability of convergence and efficiency of computations).**

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a flow-chart of the prior art Fast Super Decoupled Loadflow computation method

Fig. 2 is a flow-chart embodiment of the invented Super Super Decoupled Loadflow computation method of version SSDL-YY

Fig. 3 is a flow-chart embodiment of the invented Super Super Decoupled Loadflow: SSDL-BGX', -BGY, and -BGX versions

Fig. 4 is a flow-chart embodiment of the invented Super Super Decoupled Loadflow: SSDL-X'G_{pv}X', SSDL-YG_{pv}Y, and SSDL- XG_{pv}X versions

Fig. 5 is a flow-chart of the overall controlling method for an electrical power system involving Loadflow computation as a step which can be executed using one of the Loadflow computation methods of Figs. 1, 2, 3, 4, other variations described, their hybrid combination and/or their simple variants

Fig. 6 is a flow-chart of the simple special case of voltage control in overall controlling method of Fig. 5 for an electrical power system

Symbols

The prior art and inventions will now be described using the following symbols:

$\overline{Y}_{pq} = G_{pq} + jB_{pq}$	: (p-q) th element of nodal admittance matrix without shunts
$\overline{y} = g_p + jb_p$	: total shunt admittance at any node-p
$\overline{V}_p = e_p + jf_p = V_p\angle\theta_p$	: complex voltage of any node-p
$\overline{V}_s = e_s + jf_s = V_s\angle\theta_s$	: complex slack-node voltage
$\Delta\theta_p$, ΔV_p	: voltage angle, magnitude corrections
Δe_p, Δf_p	: real, imaginary components of voltage corrections

$P_p + jQ_p$	: net nodal injected power, calculated
$\Delta P_p + j\Delta Q_p$	: nodal power residue (mismatch)
$RP_p + jRQ_p$	: modified nodal power residue
$PSH_p + jQSH_p$	: net nodal injected power, scheduled
Φ_p	: rotation angle
m	: number of PQ-nodes
k	: number of PV-nodes
n=m+k+1	: total number of nodes
q>p	: q is the node adjacent to node-p excluding the case of q=p
[ ]	: indicates enclosed variable symbol to be a vector or a matrix
LRA	: Limiting Rotation Angle
PQ-node	: load-node (Real-Power-P and Reactive-Power-Q are specified)
PV-node	: generator-node (Real-Power-P and Voltage-Magnitude-V are specified)

Decoupled Loadflow

A class of decoupled Loadflow methods involves a system of equations for the separate calculation of voltage angle and voltage magnitude corrections. Each decoupled method comprises a system of equations (1) and (2) differing in the definition of elements of [RP], [RQ], and [Yθ] and [YV].

$$[RP] = [Y\theta]\,[\Delta\theta] \tag{1}$$

$$[RQ] = [YV]\,[\Delta V] \tag{2}$$

Successive (1θ, 1V) Iteration Scheme

In this scheme (1) and (2) are solved alternately with intermediate updating. Each iteration involves one calculation of [RP] and [Δθ] to update [θ] and then one calculation of [RQ] and [ΔV] to update [V]. The sequence of relations (3) to (6) depicts the scheme.

$$[\Delta\theta] = [Y\theta]^{-1} [RP] \tag{3}$$

$$[\theta] = [\theta] + [\Delta\theta] \tag{4}$$

$$[\Delta V] = [YV]^{-1} [RQ] \tag{5}$$

$$[V] = [V] + [\Delta V] \tag{6}$$

The scheme involves solution of system of equations (1) and (2) in an iterative manner depicted in the sequence of relations (3) to (6). This scheme requires mismatch calculation for each half iteration; because [RP] and [RQ] are calculated always using the most recent voltage values and it is block Gauss-Seidal approach. The scheme is block successive, which imparts increased stability to the solution process. This in turn improves convergence and increases the reliability of obtaining solution.

PRIOR ART: FAST SUPER DECOUPLED LOADFLOW METHO (References-3, 6, 7)

Fast Super Decoupled Loadflow (FSDL) Method

$$RP_p = (\Delta P_p Cos\Phi_p + \Delta Q_p Sin\Phi_p)/V_p \quad \text{-for PQ-nodes} \tag{7}$$

$$RQ_p = (\Delta Q_p Cos\Phi_p - \Delta P_p Sin\Phi_p)/V_p \quad \text{-for PQ-nodes} \tag{8}$$

$$Cos\Phi_p = \text{Absolute } (B_{pp} / \sqrt{(G_{pp}^2 + B_{pp}^2)}) \geq Cos(-36°) \tag{9}$$

$$Sin\Phi_p = -\text{Absolute } (G_{pp} / \sqrt{(G_{pp}^2 + B_{pp}^2)}) \geq Sin(-36°) \tag{10}$$

$$RP_p = \Delta P_p / (K_p V_p) \qquad \text{-for PV-nodes} \tag{11}$$

$$Y\theta_{pq} = \begin{cases} -Y_{pq} & \text{-for branch r/x ratio} \leq 2.0 \\ -(B_{pq} + 0.9(Y_{pq}-B_{pq})) & \text{-for branch r/x ratio} > 2.0 \\ -B_{pq} & \text{-for branches connected between two PV-nodes or} \\ & \text{a PV-node and the slack-node} \end{cases} \quad (12)$$

$$YV_{pq} = \begin{cases} -Y_{pq} & \text{-for branch r/x ratio} \leq 2.0 \\ -(B_{pq} + 0.9(Y_{pq}-B_{pq})) & \text{-for branch r/x ratio} > 2.0 \end{cases} \quad (13)$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \quad \text{and} \quad YV_{pp} = -2b_p' + \sum_{q>p} -YV_{pq} \quad (14)$$

$$b_p' = b_p \mathrm{Cos}\Phi_p \quad \text{or} \quad b_p' = b_p \quad (15)$$

$$K_p = \text{Absolute}\,(B_{pp}/Y\theta_{pp}) \quad (16)$$

Branch admittance magnitude in (12) and (13) is of the same algebraic sign as its susceptance. Elements of the two gain matrices differ in that diagonal elements of [YV] additionally contain the b' values given by relation (15) and in respect of elements corresponding to branches connected between two PV-nodes or a PV-node and the slack-node. Relations (9) and (10) with inequality sign implies that nodal rotation angles are restricted to maximum of -36 degrees. The method consists of relations (3) to (16). In two simple variations of the FSDL method, one is to make $YV_{pq}=Y\theta_{pq}$ and the other is to make $Y\theta_{pq}=YV_{pq}$. K_p is restricted to the minimum value of 0.75 determined experimentally, and it is system independent. However it can be tuned for the best possible convergence for any given system.

This prior art method involves solution of system of equations (1) and (2) in an iterative manner depicted in sequence of relations (3) to (6). Prior art method is embodied in algorithm-1, and in the flow-chart of fig.1.

Computation steps of FSDL method (Algorithm-1):

a. Read system data and assign an initial approximate solution. If better solution estimate is not available, set voltage magnitude and angle of all nodes equal to those of the slack-node. This is referred to as the **slack-start.**

b. Form nodal admittance matrix, and Initialize iteration count ITRP = ITRQ= r = 0

c. Compute Cosine and Sine of nodal rotation angles using relations (9) and (10), and store them. If they, respectively, are less than the Cosine and Sine of -36 degrees, equate them, respectively, to those of -36 degrees.

d. Form (m+k) x (m+k) size matrices [Yθ] and [YV] of (1) and (2) respectively each in a compact storage exploiting sparsity. The matrices are formed using relations (12), (13), (14), and (15). In [YV] matrix, replace diagonal elements corresponding to PV-nodes by very large value (say, 10.0**10). In case [YV] is of dimension (m x m), this is not required to be performed. Factorize [Yθ] and [YV] using the same ordering of nodes regardless of node-types and **store them using the same indexing and addressing information.** In case [YV] is of dimension (m x m), it is factorized using different ordering than that of [Yθ].

e. Compute residues [ΔP] (PQ- and PV-nodes) and [ΔQ] (at only PQ-nodes). If all are less than the tolerance (ε), proceed to step (m). Otherwise follow the next step.

f. Compute the vector of modified residues [RP] using (7) for PQ-nodes, and using (11) and (16) for PV-nodes.

g. Solve (3) for [Δθ] and update voltage angles using, [θ] = [θ] + [Δθ].

h. Set voltage magnitudes of PV-nodes equal to the specified values, and Increment the iteration count ITRP=ITRP+1 and r=(ITRP+ITRQ)/2.

i. Compute residues [ΔP] (PQ- and PV-nodes) and [ΔQ] (at PQ-nodes only). If all are less than the tolerance (ε), proceed to step (m). Otherwise follow the next step.

j. Compute the vector of modified residues [RQ] using (8) for only PQ-nodes.

k. Solve (5) for [ΔV] and update PQ-node magnitudes using [V] = [V] + [ΔV]. While solving equation (5), skip all the rows and columns corresponding to PV-nodes.

l. Increment the iteration count ITRQ=ITRQ+1 and r=(ITRP+ITRQ)/2, and Proceed to step (e)

m. Calculate line flows and output the desired results

INVENTED SUPER SUPER DECOUPLED LOADFLOW METHODS

Super Super Decoupled Loadflow: X'X'-version (SSDL-X'X')

The general method, in successive (1θ, 1V) iteration scheme represented by sequence of relations (3) to (6), can be realized as SSDL-X'X', from which manifested are many versions. The elements of [RP], [RQ], [Yθ] and [YV] are defined by (17) to (29).

$$RP_p = [\Delta P_p' + (G_{pp}'/B_{pp}')\,\Delta Q_p'] / V_p^2 \quad \text{-for PQ-nodes} \tag{17}$$

$$RQ_p = [\Delta Q_p' - (G_{pp}'/B_{pp}')\,\Delta P_p'] / V_p \quad \text{-for PQ-nodes} \tag{18}$$

$$RP_p = [\Delta P_p / (K_p * V_p^2)] \quad \text{-for PV-nodes} \tag{19}$$

$$Y\theta_{pq} = -1/X_{pq}' \quad \text{and} \quad YV_{pq} = -1/X_{pq}' \tag{20}$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \quad \text{and} \quad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \tag{21}$$

Where,

$b_p' = -2b_p\text{Cos}\Phi_p$ **or**

$b_p' = -b_p\text{Cos}\Phi_p + [QSH_p' - (G_{pp}'/B_{pp}')\,PSH_p'] / V_s^2$ **or**

$$b_p' = 2[QSH_p' - (G_{pp}'/B_{pp}')\,PSH_p'] / V_s^2 \tag{22}$$

$$\Delta P_p' = \Delta P_p\text{Cos}\Phi_p + \Delta Q_p\text{Sin}\Phi_p \quad \text{-for PQ-nodes} \tag{23}$$

$$\Delta Q_p' = \Delta Q_p\text{Cos}\Phi_p - \Delta P_p\text{Sin}\Phi_p \quad \text{-for PQ-nodes} \tag{24}$$

$$PSH_p' = PSH_p Cos\Phi_p + QSH_p Sin\Phi_p \qquad \text{-for PQ-nodes} \qquad (25)$$

$$QSH_p' = QSH_p Cos\Phi_p - PSH_p Sin\Phi_p \qquad \text{-for PQ-nodes} \qquad (26)$$

$$Cos\Phi_p = \text{Absolute}\,[B_{pp} / \surd\,(G_{pp}^2 + B_{pp}^2)] \geq Cos\,(\text{any angle from 0 to -90 degrees}) \qquad (27)$$

$$Sin\Phi_p = -\text{Absolute}\,[G_{pp} / \surd\,(G_{pp}^2 + B_{pp}^2)] \geq Sin\,(\text{any angle from 0 to -90 degrees}) \qquad (28)$$

$$K_p = \text{Absolute}\,(B_{pp}/Y\theta_{pp}) \qquad (29)$$

The factor K_p of (29) is initially restricted to the minimum of 0.75 determined experimentally; however its restriction is lowered to the minimum value of 0.6 when its average over all PV-nodes is less than 0.6. This factor is system and method independent. However it can be tuned for the best possible convergence for any given system. This statement is valid when the factor K_p is applied in the manner of equation (19) in all the methods derived in the following from the most general method SSDL-X'X'.

The definition of $Y\theta_{pq}$ in (20) is simplified because it does not explicitly state that it always takes the value of $-B_{pq}$ for a branch connected between two PV-nodes or a PV-node and the slack-node. This fact should be understood implied in all the definitions of $Y\theta_{pq}$ in this document.

However, a whole new class of methods, corresponding to all those derived in the following and prior art, results when the factor K_p is used as a multiplier in the definition of RP_p at PQ-nodes as in (30) instead of divider in RP_p at PV-nodes as given in (19). This will cause changes only in relations (17), (19), and (20) as given in (30), (31), and (32).

$$RP_p = \{[\Delta P_p' + (G_{pp}' / B_{pp}')\,\Delta Q_p'] / V_p^2\} * K_p \qquad \text{-for PQ-nodes} \qquad (30)$$

$$RP_p = \Delta P_p / V_p^2 \qquad \text{-for PV-nodes} \qquad (31)$$

$$Y\theta_{pq} = -B_{pq} \qquad \text{and} \qquad YV_{pq} = -1/X_{pq}' \tag{32}$$

The best performance of methods of this new class has been realized when the factor K_p, applied in a manner of relation (30) leading to changes as in (30) to (32), is unrestricted. That means it can take any value as given by relation (29).

Super Super Decoupled Loadflow: YY-version (SSDL-YY)

If unrestricted rotation is applied and transformed susceptance is taken as admittance value with the same algebraic sign and transformed conductance is assumed zero (reference-6), the **SSDL-X'X'** method reduces to **SSDL-YY.** Though, this method is not very sensitive to the restriction applied to nodal rotation angles, SSDL-YY presented here is the best possible experimentally arrived at method. However, it gives closely similar performance over wide range of restriction applied to the nodal rotation angles (say from -36 to -90 degrees).

$$RP_p = \Delta P_p'/V_p^2 \qquad \text{and} \qquad RQ_p = \Delta Q_p'/V_p \qquad \text{-for PQ-nodes} \tag{33}$$

$$RP_p = \Delta P_p/(K_pV_p^2) \qquad \text{-for PV-nodes} \tag{34}$$

$$Y\theta_{pq} = \begin{cases} -Y_{pq} & \text{-for branch r/x ratio} \leq 3.0 \\ -(B_{pq} + 0.9(Y_{pq}-B_{pq})) & \text{-for branch r/x ratio} > 3.0 \\ -B_{pq} & \text{-for branches connected between two PV-nodes or} \\ & \text{a PV-node and the slack-node} \end{cases} \tag{35}$$

$$YV_{pq} = \begin{cases} -Y_{pq} & \text{-for branch r/x ratio} \leq 3.0 \\ -(B_{pq} + 0.9(Y_{pq}-B_{pq})) & \text{-for branch r/x ratio} > 3.0 \end{cases} \tag{36}$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \qquad \text{and} \qquad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \tag{37}$$

$$b_p' = (QSH_p'/V_s^2) - b_p\text{Cos}\Phi_p \qquad \text{or} \qquad b_p' = 2QSH_p'/V_s^2 \tag{38}$$

where, ΔP_p', ΔQ_p', QSH_p', and K_p are defined in relations (23) to (29). However, nodal rotation angles in relations (27) and (28) be **restricted to the maximum of -48 degrees for this method**, determined experimentally for the best possible convergence from non linearity considerations.

In case of systems of only PQ-nodes and without any PV-nodes, equations (35) and (36) simply be taken as $Y\theta_{pq} = -Y_{pq}$ and $YV_{pq} = -Y_{pq}$. The factor K_p of (29) is initially restricted to the minimum of 0.75 determined experimentally; however its restriction is lowered to the minimum value of 0.6 when its average over all PV nodes is less than 0.6. This factor is system independent. However it can be tuned for the best possible convergence for any given system.

Branch admittance magnitude in (35) and (36) is of the same algebraic sign as its susceptance. Elements of the two gain matrices differ in that diagonal elements of [YV] additionally contain the b' values given by relations (37) and (38) and in respect of elements corresponding to branches connected between two PV-nodes or a PV-node and the slack-node. Relations (27) and (28) with inequality sign implies that nodal rotation angles are restricted to maximum of -48 degrees for SSDL-YY. The method consists of relation's (3) to (6), (33) to (38), and (23) to (29). In two simple variations of the SSDL-YY method, one is to make YV_{pq}=$Y\theta_{pq}$ and the other is to make $Y\theta_{pq}$=YV_{pq}.

SSDL-YY method implements successive (1θ, 1V) iteration scheme and is embodied in algorithm-2, and in flow-chart of fig.2 where double lettered steps are characteristic steps of the SSDL-YY method and are different than those of the prior art FSDL method.

Computation steps of SSDL-YY method (Algorithm-2):

a. Read system data and assign an initial approximate solution. If better solution estimate is not available, set voltage magnitude and angle of all nodes equal to those of the slack-node. This is referred to as the **slack-start**.

b. Form nodal admittance matrix, and Initialize iteration count ITRP = ITRQ= r = 0

cc. Compute Cosine and Sine of nodal rotation angles using relations (27) and (28), and store them. If they, respectively, are less than the Cosine and Sine of -48 degrees, equate them, respectively, to those of -48 degrees.

dd. Form (m+k) x (m+k) size matrices [Yθ] and [YV] of (1) and (2) respectively each in a compact storage exploiting sparsity. The matrices are formed using relations (35), (36), (37), and (38). In [YV] matrix, replace diagonal elements corresponding to PV-nodes by very large value (say, 10.0**10). In case [YV] is of dimension (m x m), this is not required to be performed. Factorize [Yθ] and [YV] using the same ordering of nodes regardless of node-types and **store them using the same indexing and addressing information.** In case [YV] is of dimension (m x m), it is factorized using different ordering than that of [Yθ].

e. Compute residues ΔP (PQ- and PV-nodes) and ΔQ (at only PQ-nodes). If all are less than the tolerance (ε), proceed to step (m). Otherwise follow the next step.

ff. Compute the vector of modified residues [RP] as in (33) for PQ-nodes, and using (34) and (29) for PV-nodes.

g. Solve (3) for [Δθ] and update voltage angles using, [θ] = [θ] + [Δθ].

h. Set voltage magnitudes of PV-nodes equal to the specified values, and Increment the iteration count ITRP=ITRP+1 and r=(ITRP+ITRQ)/2.

i. Compute residues [ΔP] (PQ- and PV-nodes) and [ΔQ] (at PQ-nodes only). If all are less than the tolerance (ε), proceed to step (m). Otherwise follow the next step.

j. Compute the vector of modified residues [RQ] as in (33) for only PQ-nodes.

k. Solve (5) for [ΔV] and update PQ-node magnitudes using [V] = [V] + [ΔV]. While solving equation (5), skip all the rows and columns corresponding to PV-nodes.

l. Increment the iteration count ITRQ=ITRQ+1 and r=(ITRP+ITRQ)/2, and Proceed to step (e)

m. Calculate line flows and output the desired results

Super Super Decoupled Loadflow: XX-version (SSDL-XX)

If no (zero) rotation is applied, the **SSDL-X'X'** method reduces to **SSDL-XX,** which is the simplest form of SSDL-X'X'. The **SSDL-XX** method comprises relations (3) to (6), (39) to (45), and (29).

$$RP_p = [\Delta P_p + (G_{pp} / B_{pp})\ \Delta Q_p] / V_p^2 \qquad \text{-for PQ-nodes} \qquad (39)$$

$$RQ_p = [\Delta Q_p - (G_{pp} / B_{pp})\ \Delta P_p] / V_p \qquad \text{-for PQ-nodes} \qquad (40)$$

$$RP_p = \Delta P_p / (K_p V_p^2) \qquad \text{-for PV-nodes} \qquad (41)$$

$$Y\theta_{pq} = \begin{cases} -1.0/X_{pq} & \text{-for all other branches} \\ -B_{pq} & \text{-for branches connected between two PV-nodes or a PV-node and the slack-node} \end{cases} \qquad (42)$$

$$YV_{pq} = -1.0/X_{pq} \qquad \text{-for all branches} \qquad (43)$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \qquad \text{and} \qquad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \qquad (44)$$

$$b_p' = -2b_p \qquad \textbf{or}$$
$$b_p' = -b_p + [QSH_p - (G_{pp} / B_{pp})\ PSH_p]/V_s^2 \qquad \textbf{or}$$
$$b_p' = 2[QSH_p - (G_{pp} / B_{pp})\ PSH_p]/V_s^2 \qquad (45)$$

where, K_p is defined in relation (29). This is the simplest method with very good performance for distribution networks in absence of PV-nodes (for systems containing only PQ-nodes). The large value of the difference [(1/X)-B], particularly for high R/X ratios branches connected to PV-nodes, creates modeling error when PV-nodes are present in a system.

Super Super Decoupled Loadflow: BX-version (SSDL-BX)

If super decoupling is applied only to QV-sub problem, the **SSDL-XX** method reduces to **SSDL-BX,** which makes it perform better for systems containing PV-nodes. The **SSDL-BX** method comprises relations (3) to (6), (46) to (48), (44) and (45). This method can be referred to as Advanced BX-Fast Decoupled Loadflow.

$$RP_p = \Delta P_p / V_p^2 \qquad \text{-for all nodes} \tag{46}$$

$$RQ_p = [\Delta Q_p - (G_{pp} / B_{pp})\, \Delta P_p] / V_p \qquad \text{-for PQ-nodes} \tag{47}$$

$$Y\theta_{pq} = -B_{pq} \qquad \text{and} \qquad YV_{pq} = -1/X_{pq} \tag{48}$$

It should be noted that Amerongen's General-purpose Fast Decoupled Loadflow method of reference-5 has turned out to be an approximation of this method. The approximation involved is only in relation (47). However, numerical performance is found to be only slightly better but more reliable than that of the Amerongen's method.

Super Super Decoupled Loadflow: X'B'-version (SSDL-X'B')

$$RP_p = [\Delta P_p' + (G_{pp}'/B_{pp}')\, \Delta Q_p'] / V_p^2 \qquad \text{-for PQ-nodes} \tag{49}$$

$$RQ_p = \Delta Q_p' / V_p \qquad \text{-for PQ-nodes} \tag{50}$$

$$RP_p = [\Delta P_p / (K_p * V_p^2)] \qquad \text{-for PV-nodes} \tag{51}$$

$$Y\theta_{pq} = -1/X_{pq}' \qquad \text{and} \qquad YV_{pq} = -B_{pq}' \tag{52}$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \qquad \text{and} \qquad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \tag{53}$$

Where, $b_p' = -2b_p \text{Cos}\Phi_p$ **or**

$b_p' = -b_p \text{Cos}\Phi_p + QSH_p'/V_s^2$ **or**

$$b_p' = 2QSH_p'/V_s^2 \tag{54}$$

Where, $\Delta P_p'$, $\Delta Q_p'$, PSH_p', QSH_p', $\text{Cos}\Phi_p$, $\text{Sin}\Phi_p$, K_p are defined in (23)to(29).This method consists of relations (3) to (6), (49) to (54), and (23) to (29). Best performance of this method could be achieved by restricting Φ_p in (27) and (28) to less than or equal to -48°.

Super Super Decoupled Loadflow: YB'-version (SSDL-YB')

The relation (49) in SSDL-X'B' implies unrestricted Φ_p is applied and it can take values up to -90 degrees. Therefore, (49) can be modified to (55) with consequent modification of (52) into (56).

$$RP_p = [\Delta P_p * \text{Absolute}\,[B_{pp} / \surd\,(G_{pp}^2 + B_{pp}^2)] + \Delta Q_p * [-\text{Absolute}\,[B_{pp} / \surd\,(G_{pp}^2 + B_{pp}^2)]] / V_p^2 \quad \text{-for PQ-nodes} \quad (55)$$

$$Y\theta_{pq} = -Y_{pq} \quad \text{and} \quad YV_{pq} = -B_{pq}' \quad (56)$$

This method consists of relations (3) to (6), (55), (50), (51), (56), (53) and (54), and (23) to (29). Best performance of this method could be achieved by restricting Φ_p in (27) and (28) to less than or equal to -48 degrees. Where, $\Delta P_p'$, $\Delta Q_p'$, PSH_p' , QSH_p' , $Cos\Phi_p$, $Sin\Phi_p$, K_p are defined in (23) to (29).

Super Super Decoupled Loadflow: B'X'-version (SSDL-B'X')

$$RP_p = \Delta P_p' / V_p^2 \quad \text{-for PQ-nodes} \quad (57)$$

$$RQ_p = [\Delta Q_p' - (G_{pp}'/B_{pp}')\,\Delta P_p'] / V_p \quad \text{-for PQ-nodes} \quad (58)$$

$$RP_p = [\Delta P_p / (K_p * V_p^2)] \quad \text{-for PV-nodes} \quad (59)$$

$$Y\theta_{pq} = -B_{pq}' \quad \text{and} \quad YV_{pq} = -1/X_{pq}' \quad (60)$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \quad \text{and} \quad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \quad (61)$$

Where,
$$b_p' = -2b_p Cos\Phi_p \quad \text{or}$$
$$b_p' = -b_p Cos\Phi_p + [QSH_p' - (G_{pp}'/B_{pp}')\,PSH_p']/V_s^2 \quad \text{or}$$
$$b_p' = 2[QSH_p' - (G_{pp}'/B_{pp}')\,PSH_p']/V_s^2 \quad (62)$$

Where, $\Delta P_p'$, $\Delta Q_p'$, PSH_p', QSH_p', $Cos\Phi_p$, $Sin\Phi_p$, K_p are defined in (23)to (29).This method consists of relations (3) to (6), (57) to (62), and (23) to (29). Best performance of this method could be achieved by restricting Φ_p in (27) and (28) to less than equal to -48°.

Super Super Decoupled Loadflow: B'Y-version (SSDL- B'Y)

The realtion (58) in SSDL-B'X' implies unrestricted Φ_p is applied and it can take values up to -90 degrees. Therefore, (58) can be modified to (63) with consequent modification of (60) into (64).

$$RQ_p = [\Delta Q_p * \text{Absolute}\ [B_{pp} / v\,(G_{pp}{}^2 + B_{pp}{}^2)] - \Delta P_p * [-\text{Absolute}\ [B_{pp} / v\,(G_{pp}{}^2 + B_{pp}{}^2)]] / V_p{}^2 \quad \text{-for PQ-nodes} \tag{63}$$

$$Y\theta_{pq} = -B_{pq}' \quad \text{and} \quad YV_{pq} = -Y_{pq} \tag{64}$$

This method consists of relations (3) to (6), (57), (63), (59), (64), (61) and (62), and (23) to (29). Best performance of this method could be achieved by restricting Φ_p in (27) and (28) to less than or equal to -48 degrees. Where, $\Delta P_p'$, $\Delta Q_p'$, PSH_p' , QSH_p' , $Cos\Phi_p$, $Sin\Phi_p$, K_p are defined in (23) to (29).

Simultaneous (1V, 1θ) Iteration Scheme

An ideal to be approached for the decoupled Loadflow methods is the constant matrix Loadflow of reference-6 referred in this document as BGGB-method. In an attempt to imitate it, a decoupled class of methods with simultaneous (1V, 1θ) iteration scheme depicted by sequence of relations (65) to (69) is invented. This scheme involves only one mismatch calculation in an iteration. The correction vector is calculated in two separate parts without intermediate updating. Each iteration involves one calculation of [RQ], [ΔV], and [RP], [Δθ] to update [V] and [θ].

$$[\Delta V] = [YV]^{-1} [RQ] \tag{65}$$

$$[RP] = [\Delta P/V] - [G]\,[\Delta V] \qquad (66)$$

$$[\Delta\theta] = [Y\theta]^{-1}\,[RP] \qquad (67)$$

$$[\theta] = [\theta] + [\Delta\theta] \qquad (68)$$

$$[V] = [V] + [\Delta V] \qquad (69)$$

In this invented class, each method differs only in the definition of elements of [RQ] and [YV]. The accuracy of methods depends only on the accuracy of calculation of [ΔV]. The greater the angular spread of branches terminating at PQ-nodes, the greater the inaccuracy in the calculation of [ΔV].

Super Super Decoupled Loadflow: BGX'-version (SSDL-BGX')

Numerical performance could further be improved by organizing the solution in a simultaneous (1V, 1θ) iteration scheme represented by sequence of relations (65) to (69). The elements of [RP], [RQ], [Yθ] and [YV] are defined by (70) to (74).

$$RQ_p = [\Delta Q_p' - (G_{pp}' / B_{pp}')\,\Delta P_p'] / V_p \qquad \text{-for PQ-nodes} \qquad (70)$$

$$RP_p = (\Delta P_p/V_p) - \sum_{q=1}^{m} G_{pq}\Delta V_q \qquad \text{-for all nodes} \qquad (71)$$

$$Y\theta_{pq} = -B_{pq} \qquad \text{and} \qquad YV_{pq} = -1/X_{pq}' \qquad (72)$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \qquad \text{and} \qquad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \qquad (73)$$

$$b_p' = -2b_p \mathrm{Cos}\Phi_p \qquad \textbf{or}$$

$$b_p' = -b_p \mathrm{Cos}\Phi_p + [QSH_p' - (G_{pp}'/B_{pp}')\,PSH_p']/V_s^2 \qquad \textbf{or}$$

$$b_p' = 2[QSH_p' - (G_{pp}'/B_{pp}')\,PSH_p']/V_s^2 \qquad (74)$$

Where, $\Delta P_p'$, $\Delta Q_p'$, PSH_p' , QSH_p' , $Cos\Phi_p$, $Sin\Phi_p$ are defined in (23) to (28).The SSDL-BGX' method comprises relations (65) to (74), and (23) to (28). Best possible convergence could be achieved by restricting rotations (Φ_p) in the range (-10° to -20°) in relations (27) and (28). The method is embodied in algorithm-3 and in the flow-chart of Fig.3.

Super Super Decoupled Loadflow: BGY-version (SSDL-BGY)

If unrestricted rotation is applied and transformed susceptance is taken as admittance values and transformed conductance is assumed zero (reference-6), the SSDL-BGX' method reduces to SSDL-BGY as defined by relations (75) to (79).

$$RQ_p = \Delta Q_p'/V_p = (\Delta Q_p Cos\Phi_p - \Delta P_p Sin\Phi_p)/V_p \qquad \text{-for PQ-nodes} \qquad (75)$$

$$RP_p = (\Delta P_p/V_p) - \sum_{q=1}^{m} G_{pq}\Delta V_q \qquad \text{-for all nodes} \qquad (76)$$

$$Y\theta_{pq} = -B_{pq} \qquad \text{and} \qquad YV_{pq} = -Y_{pq} \qquad (77)$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \qquad \text{and} \qquad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \qquad (78)$$

$$b_p' = -2b_p Cos\Phi_p \qquad \textbf{or}$$
$$b_p' = -b_p Cos\Phi_p + (QSH_p Cos\Phi_p - PSH_p Sin\Phi_p)/V_s^2 \qquad \textbf{or}$$
$$b_p' = 2(QSH_p Cos\Phi_p - PSH_p Sin\Phi_p)/V_s^2 \qquad (79)$$

The SSDL-BGY method comprises relations (65) to (69), and (75) to (79). It is the special case of the SSDL-BGX' method.

Super Super Decoupled Loadflow: BGX-version (SSDL-BGX)

If no (zero) rotation is applied, the SSDL-BGX' method reduces to SSDL-BGX as defined by relations (80) to (84).

$RQ_p = [\Delta Q_p - (G_{pp} / B_{pp})\Delta P_p] / V_p$ -for PQ-nodes (80)

$RP_p = (\Delta P_p/V_p) - \sum_{q=1}^{m} G_{pq}\Delta V_q$ -for all nodes (81)

$Y\theta_{pq} = -B_{pq}$ and $YV_{pq} = -1/X_{pq}$ (82)

$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq}$ and $YV_{pp} = b_p' + \sum_{q>p} -YV_{pq}$ (83)

$b_p' = -2b_p \text{Cos}\Phi_p$ or

$b_p' = -b_p \text{Cos}\Phi_p + [QSH_p - (G_{pp} / B_{pp})PSH_p]/V_s^2$ or

$b_p' = 2[QSH_p - (G_{pp} / B_{pp})PSH_p]/V_s^2$ (84)

The SSDL-BGX method comprises relations (65) to (69), and (80) to (84). It is again the special case of the SSDL-BGX' method.

Computation steps of SSDL-BGX', SSDL-BGY and SSDL-BGX methods (Algorithm-3):

a. Read system data and assign an initial approximate solution. If better solution estimate is not available, set voltage magnitude and angle of all nodes equal to those of the slack-node. This is referred to as the **slack-start.**

b. Form nodal admittance matrix, and Initialize iteration count ITR = 0.

ccc. Compute Sine and Cosine of nodal rotation angles using relations (28) and (27), and store them. If they, respectively, are less than the Sine and Cosine of any angle set (say in the range -10 to -20 degrees), equate them, respectively, to those of the same angle in the range -10 to -20 degrees. In case of zero rotation, Sine and Cosine value vectors are not required to be stored.

ddd. Form (m+k) x (m+k) size matrices [Yθ] and [YV] of (1) and (2) respectively each in a compact storage exploiting sparsity

1) In case of SSDL-BGX'-method, the matrices are formed using relations (72), (73), and (74)

2) In case of SSDL-BGY-method, the matrices are formed using relations (77), (78), and (79)
3) In case of SSDL-BGX-method, the matrices are formed using relations (82), (83), and (84)

In [YV] matrix, replace diagonal elements corresponding to PV-nodes by very large value (say, 10.0**10). In case [YV] is of dimension (m x m), this is not required to be performed. Factorize [Yθ] and [YV] using the same ordering of nodes regardless of node-types and **store them using the same indexing and addressing information.** In case [YV] is of dimension (m x m), it is factorized using different ordering than that of [Yθ].

e. Compute residues ΔP (PQ- and PV-nodes) and ΔQ (at only PQ-nodes). If all are less than the tolerance (ε), proceed to step (m). Otherwise follow the next step.

fff. Compute the vector of modified residues [RQ] using (70) in case of SSDL-BGX' , using (75) in case of SSDL-BGY, and using (80) in case of SSDL-BGX method for only PQ-nodes. Solve (65) for [ΔV]. While solving equation (65), skip all the rows and columns corresponding to PV-nodes. Compute the vector of modified residues [RP] using (71) or (76) or (81). Solve (67) for [Δθ].

ggg. Update voltage angles using, [θ] = [θ] + [Δθ]. and update PQ-node voltage magnitudes using [V] = [V] + [ΔV].

hhh. Set voltage magnitudes of PV-nodes equal to the specified values, and Increment the iteration count ITR=ITR+1, and proceed to step (e).

m. Calculate line flows and output the desired results

Triple lettered steps are characteristic steps of algorithm-3. The SSDL-BGX', SSDL-BGY and SSDL-BGX methods differ only in steps-ccc and -ddd defining gain matrices, and step-fff for calculating [RP] and [RQ]. Fig.3 is the flow-chart embodiment of algorithm-3.

Super Super Decoupled Loadflow: X'G_{pv}X'-version (SSDL- X'G_{pv}X')

Numerical performance could also be improved by organizing the solution in a simultaneous (1V, 1θ) iteration scheme represented by sequence of relations (65) to (69).

The elements of [RP], [RQ], [Yθ] and [YV] for this method are defined by (85) to (91).

$$RP_p = \{[\Delta P_p' + (G_{pp}'/B_{pp}')\Delta Q_p'] / V_p^2\} - (g_p'\Delta V_p) \quad \text{-for PQ-nodes} \tag{85}$$

$$RQ_p = [\Delta Q_p' - (G_{pp}/B_{pp}')\Delta P_p'] / V_p \quad \text{-for PQ-nodes} \tag{86}$$

$$RP_p = [(\Delta P_p/V_p^2) - \sum_{q=1}^{m} G_{pq}\,\Delta V_q] / K_p \quad \text{-for PV-nodes} \tag{87}$$

$$Y\theta_{pq} = -1/X_{pq}' \quad \text{and} \quad YV_{pq} = -1/X_{pq}' \tag{88}$$

$$Y\theta_{pp} = \sum_{q>p} -Y\theta_{pq} \quad \text{and} \quad YV_{pp} = b_p' + \sum_{q>p} -YV_{pq} \tag{89}$$

$$\begin{aligned} b_p' &= -2b_p\mathrm{Cos}\Phi_p && \textbf{or} \\ b_p' &= -b_p\mathrm{Cos}\Phi_p + [QSH_p' - (G_{pp}'/B_{pp}')PSH_p']/V_s^2 && \textbf{or} \\ b_p' &= 2[QSH_p' - (G_{pp}'/B_{pp}')PSH_p']/V_s^2 \end{aligned} \tag{90}$$

$$\begin{aligned} g_p' &= 2b_p\mathrm{Sin}\Phi_p && \textbf{or} \\ g_p' &= b_p\mathrm{Sin}\Phi_p + [PSH_p' + (G_{pp}'/B_{pp}')QSH_p']/V_s^2 && \textbf{or} \\ g_p' &= 2[PSH_p' + (G_{pp}'/B_{pp}')QSH_p']/V_s^2 \end{aligned} \tag{91}$$

Where, $\Delta P_p'$, $\Delta Q_p'$, PSH_p' , QSH_p' , $\mathrm{Cos}\Phi_p$, $\mathrm{Sin}\Phi_p$, K_p are defined in (23) to (29).Again, if unrestricted rotation is applied and transformed susceptance is taken as admittance values and transformed conductance is assumed zero (reference-6), the **SSDL-X'G_{pv}X'** method reduces to **SSDL-YG_{pv}Y.** If no (zero) rotation is applied, the **SSDL-X'G_{pv}X'** method reduces to **SSDL-XG_{pv}X.** The SSDL-X'G_{pv}X' method comprises relations (65) to (69), (85) to (91), and (23) to (29). It is embodied in algorithm-4 and in the flow-chart of Fig.4.

Computation steps of SSDL-X'G_{pv}X', SSDL-YG_{pv}Y and SSDL-XG_{pv}X methods (Algorithm-4):

a. Read system data and assign an initial approximate solution. If better solution estimate is not available, set voltage magnitude and angle of all nodes equal to those of the slack-node. This is referred to as the **slack-start.**

b. Form nodal admittance matrix, and Initialize iteration count ITR= 0.

ccc. Compute Sine and Cosine of nodal rotation angles using relations (28) and (27), store them. If they, respectively, are less than the Sine and Cosine of any angle set (say 0 to -90 degrees), equate them, respectively, to those of the same angle in the range 0 to -90 degrees. In case of zero rotation, Sine and Cosine vectors are not required to be stored.

dddd. Form (m+k) x (m+k) size matrices [Yθ] and [YV] of (1) and (2) respectively each in a compact storage exploiting sparsity using relations (88), (89), and (90).

In [YV] matrix, replace diagonal elements corresponding to PV-nodes by very large value (say, 10.0**10). In case [YV] is of dimension (m x m), this is not required to be performed. Factorize [Yθ] and [YV] using the same ordering of nodes regardless of node-types and **store them using the same indexing and addressing information.** In case [YV] is of dimension (m x m), it is factorized using different ordering than that of [Yθ].

e. Compute residues ΔP (PQ- and PV-nodes) and ΔQ (at only PQ-nodes). If all are less than the tolerance (ε), proceed to step (m). Otherwise follow the next step.

ffff. Compute [RQ] using (86) for only PQ-nodes. Solve (65) for [ΔV]. While solving equation (65), skip all the rows and columns corresponding to PV-nodes. Compute the vector of modified residues [RP] using relations (85), (87), and (29). Solve (67) for [Δθ].

ggg. Update voltage angles using, [θ] = [θ] + [Δθ]. and update PQ-node voltage magnitudes using [V] = [V] + [ΔV].

hhh. Set voltage magnitudes of PV-nodes equal to the specified values, and Increment the iteration count ITR=ITR+1, and proceed to step (e)

m. Calculate line flows and output the desired results

Four lettered steps are characteristic steps of algorithm-4. This method is useful particularly for distribution systems without PV-nodes. Fig.4 is the flow-chart embodiment of algorithm-4.

Common Statements Concerning all methods:

In all the prior art and invented models [Yθ] and [YV] are real, sparse, symmetrical and built only from network elements. Since they are constant, they need to be factorized once only at the start of the solution. Equations (1) and (2) are to be solved repeatedly by forward and backward substitutions.

[Yθ] and [YV] are of the same dimensions (m+k) x (m+k) when only a row/column of the slack-node is excluded and both are triangularized using the same ordering regardless of the node-types. For a row/column corresponding to a PV-node excluded in [YV], use a large diagonal to mask out the effects of the off-diagonal terms. When the node is switched to the PQ-type the row/column is reactivated by removing the large diagonal. This technique is especially useful in the treatment of PV-nodes in the matrix [YV].

It is invented to make this technique efficient while solving (5) or (65) for [ΔV] by skipping all PV-nodes and factor elements with indices corresponding to PV-nodes. In other words efficiency can be realized by skipping operations on rows/columns corresponding to PV-nodes in the forward-backward solution of (5) or (65). This has been implemented and time saving of about 4% of the total solution time (including input/output) could be realized in 14-14 iterations required to solve 118-node system with the uniform R-scale factor of 4 applied. **It should be noted that the same indexing and addressing information can be used for the storage of both matrices as they are of the same dimension and sparsity structure.**

ALGORITHMS using GLOBAL CORRECTIONS

The algorithms-1, -2, -3, and -4 in the above involve incremental (or local) corrections. All the above algorithms can be organized to produce corrections to the initial estimate

solution. It involves storage of the vectors of modified residues and replacing the relations (17), (18), (19) by (92), (93), (94) respectively, and (4) or (68) and (6) or (69) respectively by (95) and (96). Superscript '0' in relations (95) and (96) indicates the initial solution estimate.

$$RP_p^r = [(\Delta P_p^r)' + (G_{pp}'/B_{pp}')(\Delta Q_p^r)']/(V_p^r)^2 + RP_p^{(r-1)} \qquad (92)$$

$$RQ_p^r = [(\Delta Q_p^r)' - (G_{pp}'/B_{pp}')(\Delta P_p^r)']/(V_p^r)^2 + RQ_p^{(r-1)} \qquad (93)$$

$$RP_p^r = \Delta P_p^r / [K_p(V_p^r)^2] + RP_p^{(r-1)} \qquad (94)$$

$$\theta_p^r = \theta_p^0 + \Delta\theta_p^r \qquad (95)$$

$$V_p^r = V_p^0 + \Delta V_p^r \qquad (96)$$

RECTANGULAR COORDINATE FORMULATIONS OF INVENTED LOADFLOW METHODS

This involves following changes in the equations describing the loadflow models formulated in polar coordinates.

(i) Replace θ and $\Delta\theta$ respectively by f and Δf in equations (1),(3), (4), (67), (68) and (95)

(ii) Replace V and ΔV respectively by e and Δe in equations (2), (5), (6), (65), (66), (69) and (96)

(iii) Replace V_p by e_p and V_s by e_s in equations (17) to (19), (22), (30), (31), (33), (34), (38) to (41), (45) to (47), (49) to (51), (54), (55), (57) to (59), (62), (63), (70), (71), (74) to (76), (79) to (81), (84) to (87), (90), (91). The subscript 's' indicates the slack-node variable.

(iv) After calculation of corrections to the imaginary part of complex voltage (Δf) of PV-nodes and updating the imaginary component (f) of PV-nodes, calculate real component by:

$$e_p = \sqrt{V_{sp}^2 - f_p^2} \quad (97)$$

APPENDIX

Transformation of Branch Admittance

The branch admittance transformation for symmetrical gain matrices of the methods described in the above is given by the following steps:

1. Compute: $\Phi_p = \arctan (G_{pp}/B_{pp})$ and

$$\Phi_q = \arctan (G_{qq}/B_{qq}) \quad (98)$$

2. Compute the average of rotations at the terminal nodes (p and q) of a branch:

$$\Phi_{av} = (\Phi_p + \Phi_q)/2 \quad (99)$$

3. Compare Φ_{av} with the Limiting Rotation Angle (LRA) and let Φ_{av} to be the smaller of the two:

$$\Phi_{av} = \text{minimum} (\Phi_{av}, \text{LRA}) \quad (100)$$

4. Compute transformed pq-th element of the admittance matrix:

$$G_{pq}' + jB_{pq}' = (\text{Cos } \Phi_{av} + j \text{ Sin } \Phi_{av}) (G_{pq} + jB_{pq}) \quad (101)$$

5. Note that the transformed branch reactance is:

$$X_{pq}' = B_{pq}'/(G_{pq}'^2 + B_{pq}'^2) \qquad \text{and similarly,} \qquad (102)$$

$$X_{pp}' = B_{pp}'/\,(G_p{}^2 + B_{pp}'^2) \qquad (103)$$

In the description above X_{pq}' is the transformed branch reactance defined by equation (103) and B_{pq}' is the corresponding transformed element of the susceptance matrix. G_{pp}' and B_{pp}' are diagonal elements obtained from (102).

SOME POSSIBLE SIMPLE VARIATIONS OF SSDL-METHODS

1. Simple obvious modifications are the use of V_p and V_p^2 interchangeably in all expressions of RP_p, and the use of 1.0 for V_s^2 in all expressions of b_p' involving the term V_s^2
2. b_p' can also take values without transformation of b_p and QSH_p
3. Explicit algorithmic steps are not given for many variants of SSDL-X'X' except SSDL-YY, They are obvious from their descriptions and are similar to those of SSDL-YY method

EXPLANATORY STATEMENTS

The system stores a representation of the reactive capability characteristic of each machine and these characteristics act as constraints on the reactive power, which can be calculated for each machine.

While the description above refers to particular embodiments of the present invention, it will be understood that many modifications may be made without departing from the spirit thereof. The accompanying claims are intended to cover such modifications as would fall within the true scope and spirit of the present invention.

The presently disclosed embodiments are therefore to be considered in all respect as illustrative and not restrictive, the scope of the invention being indicated by the appended claims in addition to the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

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CLAIMS

The present invention is applicable to systems to process Loadflow computation by means of modified real and reactive power residues, and gain matrices derived from the Jacobian matrix. The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of controlling security (over load, under/over voltage) in a power system, comprising the steps of:

obtaining on-line data of nodal injections, voltages and phases at main nodes, and open/close status of circuit breakers in the power system,

establishing initial specifications of controlled parameters (real and reactive power at PQ-nodes, real power and voltage magnitude at PV-nodes, and transformer turns ratios etc.),

performing Loadflow computation at said nodes of the power system by a Super Super Decoupled computation in any of the Super Super Decoupled Loadflow methods or any of their hybrid combination or simple variants employing corresponding gain matrices derived from a super decoupled Jacobian matrix for real power with respect to angle and a super decoupled Jacobian matrix for reactive power with respect to voltage, and involving triangular factorization of said gain matrices and computing of discrepancy of real power and reactive power from specified values through such nodes,

said computing including introducing variables representing quotients of the transformed discrepancies from specified values of real and reactive power flowing in through each node divided by voltage, or square of the voltage in case of transformed real power mismatches in methods employing (1θ, 1V) iteration scheme, on each node, and using such variables to calculate values of angle and voltage for said transformed discrepancies from specified values of real and reactive power flowing in through each node, by using triangular factorization of said gain matrices for real and reactive power,

initiating said Loadflow computation with guess solution of the same voltage magnitude and angle as those of the slack (reference) node referred to as slack start,

restricting nodal transformation angle to maximum -48 degrees, applied to complex power injection in computing said transformed discrepancies from specified values of real and reactive power flowing in through each node,

evaluating the computed Loadflow for security (over load, under/over voltage),

correcting one or more controlled parameters with said correction (amount of over load and/or under/over voltage) values and repeating the computing and evaluating steps until evaluating step finds a good power system (no over load, no under/over voltage), and

effecting a change in the voltages and phases at said nodes of the power system by actually implementing the finally obtained values of controlled parameters after evaluating step finds a good power system.

2. A method as defined in claim1 wherein said Super Super Decoupled methods, employing successive (1θ, 1V) iteration scheme, of Loadflow computation are characterized in modifying the transformed real power residue at a PQ-node and real power residue at a PV-node by dividing them by squared voltage magnitude multiplied by a factor determined as a ratio of a diagonal element of susceptance matrix to a diagonal element of corresponding said gain matrix derived from transformed Jacobian matrix for real power with respect to angle.

3. A method as defined in claim1 wherein said Super Super Decoupled methods, employing simultaneous (1V, 1θ) iteration scheme, of Loadflow computation are characterized in that they involve only one time calculation of real and reactive power residues in an iteration unlike two calculations in successive (1θ, 1V) iteration scheme, and thereby achieving consequent speed-up.

4. A simple system/method of controlling generator and transformer voltages of more elaborate method of security control defined in claim 1 can be realised in a

system for controlling generator and transformer voltages in an electrical power utility containing plurality of electromechanical rotating machines, transformers and electrical loads connected in a network, each machine having a reactive power characteristic and excitation element which is controllable for adjusting the reactive power generated or absorbed by the machine, and some of the transformers having controllable taps for adjusting terminal voltage, said system comprising:

means defining any of Super Super Decoupled models of the network for providing an indication of the quantity of reactive power to be supplied by generators including at a reference node in dependence on representations of selected network electrical parameters,

machine control means connected to the said excitation element of at least one of the rotating machines for controlling the operation of the excitation element of at least one machine to produce or absorb the amount of reactive power indicated by said model means with respect to the set of representations.

5. A system as defined in claim 4 wherein the network includes a plurality of nodes each connected to at least one of: a reference generator; a rotating machine; and an electrical load, and the model has one of the 3-forms and their variants of Super Super Decoupled matrices which receives representations of selected values of the real and reactive power flow from each machine and to each load, and the model is operative for producing calculated values for the reactive power quantity to be produced or absorbed by each machine.

6. A system as defined in claim 4 wherein the utility further has at least one transformer having an adjustable transformation ratio, and said means defining a model is further operative for producing a calculated value for the transformer transformation ratio.

7. A system as defined in claim 4 wherein said machine control means are connected to said excitation element of each machine for controlling the operation of the excitation element of each machine.

8. A system as defined in claim 4 wherein said transformation ratio control means are connected to said transformer tap changing element of each transformer for controlling the operation of the transformer tap changing element of each transformer.

9. A method for controlling generator and transformer voltages in an electrical power utility containing plurality of electromechanical rotating machines, transformers and electrical loads connected in a network, each machine having a reactive power characteristic and excitation element which is controllable for adjusting the reactive power generated or absorbed by the machine, and some of the transformers having controllable taps for adjusting terminal voltage, said method comprising:

creating any of said Super Super Decoupled models of the network for providing an indication of the quantity of reactive power to be supplied by the generators in dependence on representations of selected network electrical parameters,

controlling the operation of the excitation element of at least one machine to produce or absorb the amount of reactive power indicated by any of the said Super Super decoupled models with respect to the set of specified parameters.

10. A method as defined in claim 9 wherein said step of controlling is carried out to control the excitation element of each machine.

11. A method as defined in claim 9 wherein said step of controlling is carried out to control the tap-changing element of each transformer.

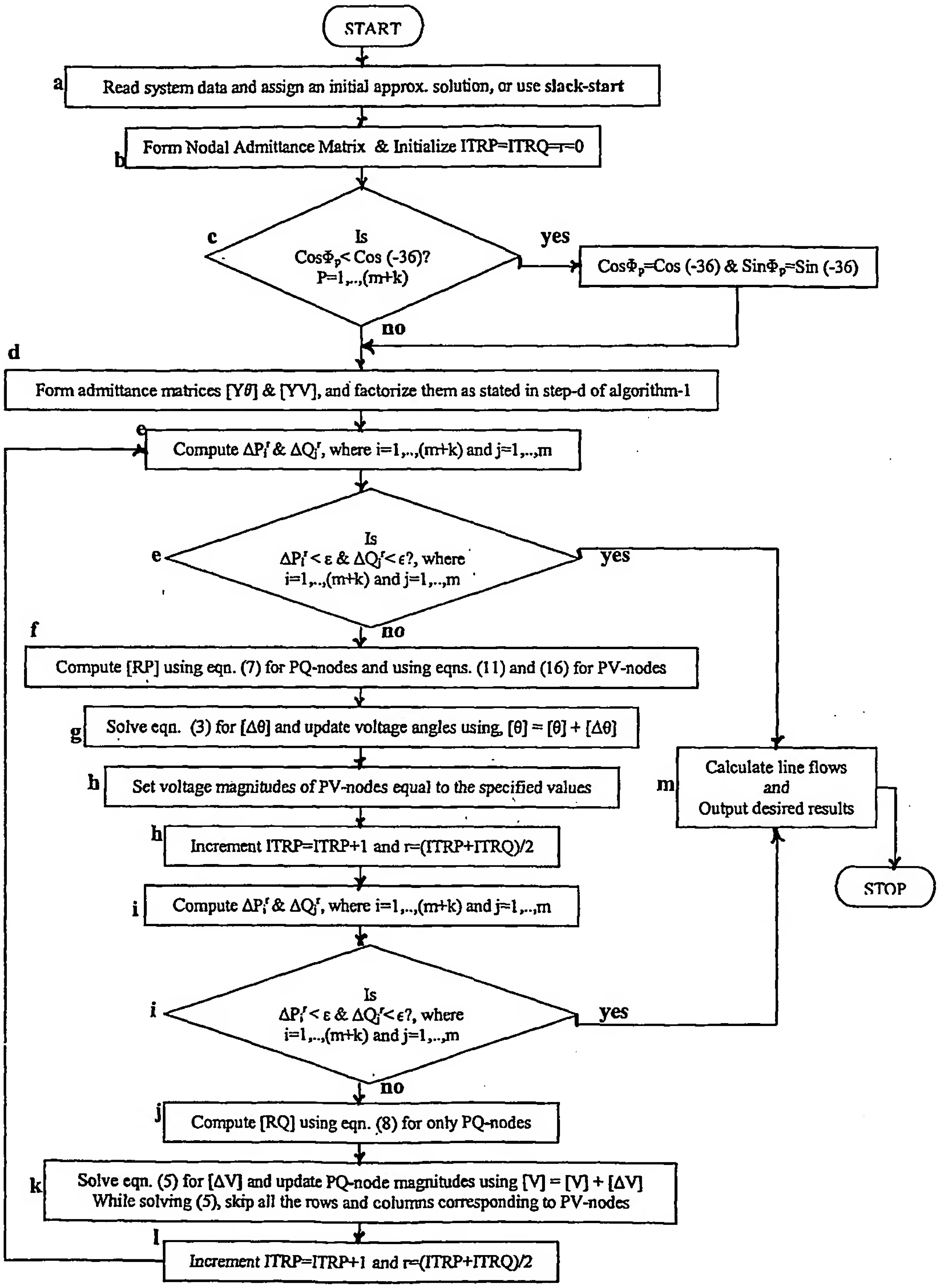

Fig.1: PRIOR ART: Flow-chart of FSDL solution algorithm-1

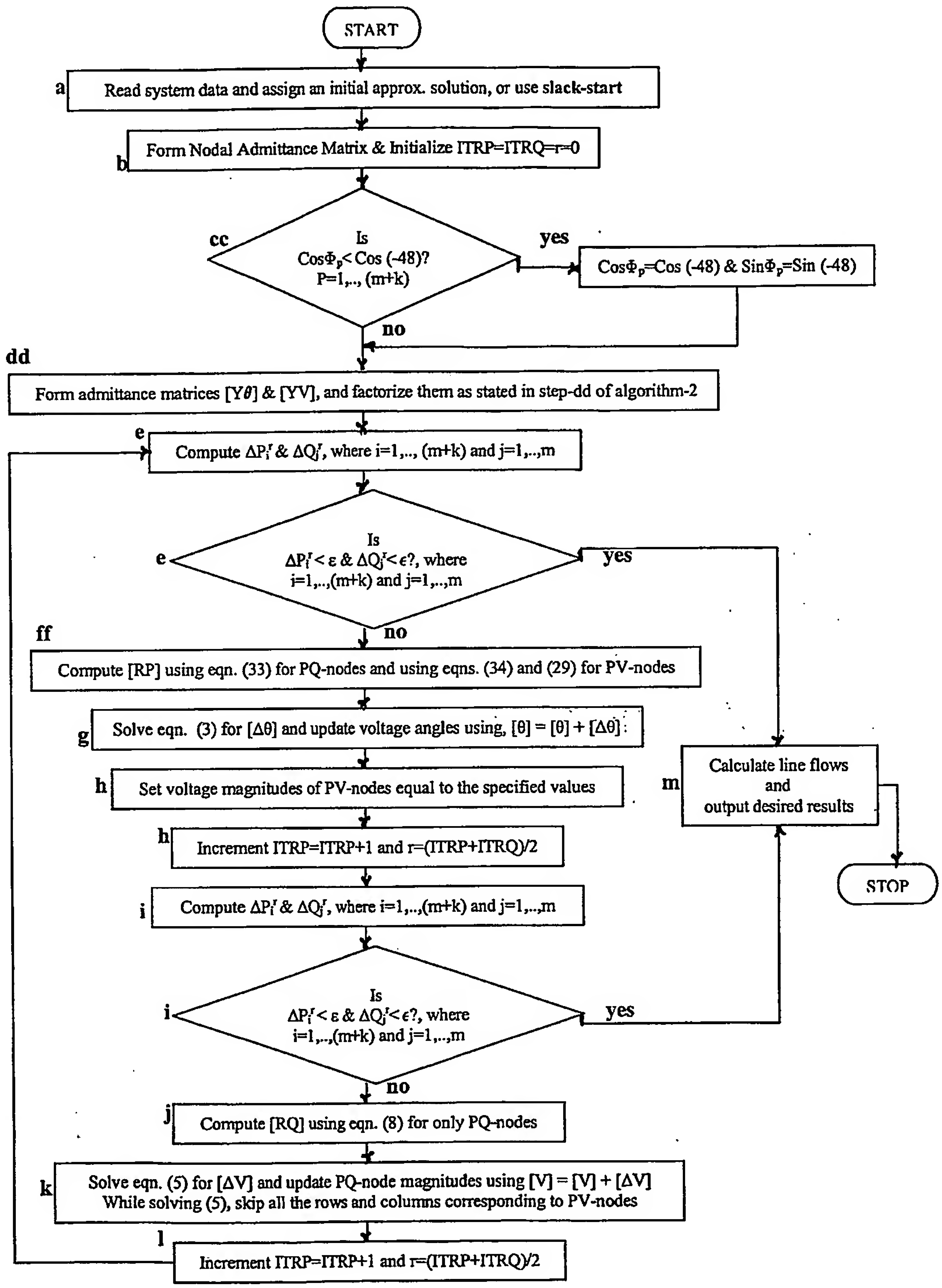

Fig.2: **Invention: Flow-chart of SSDL-YY solution algorithm-2**

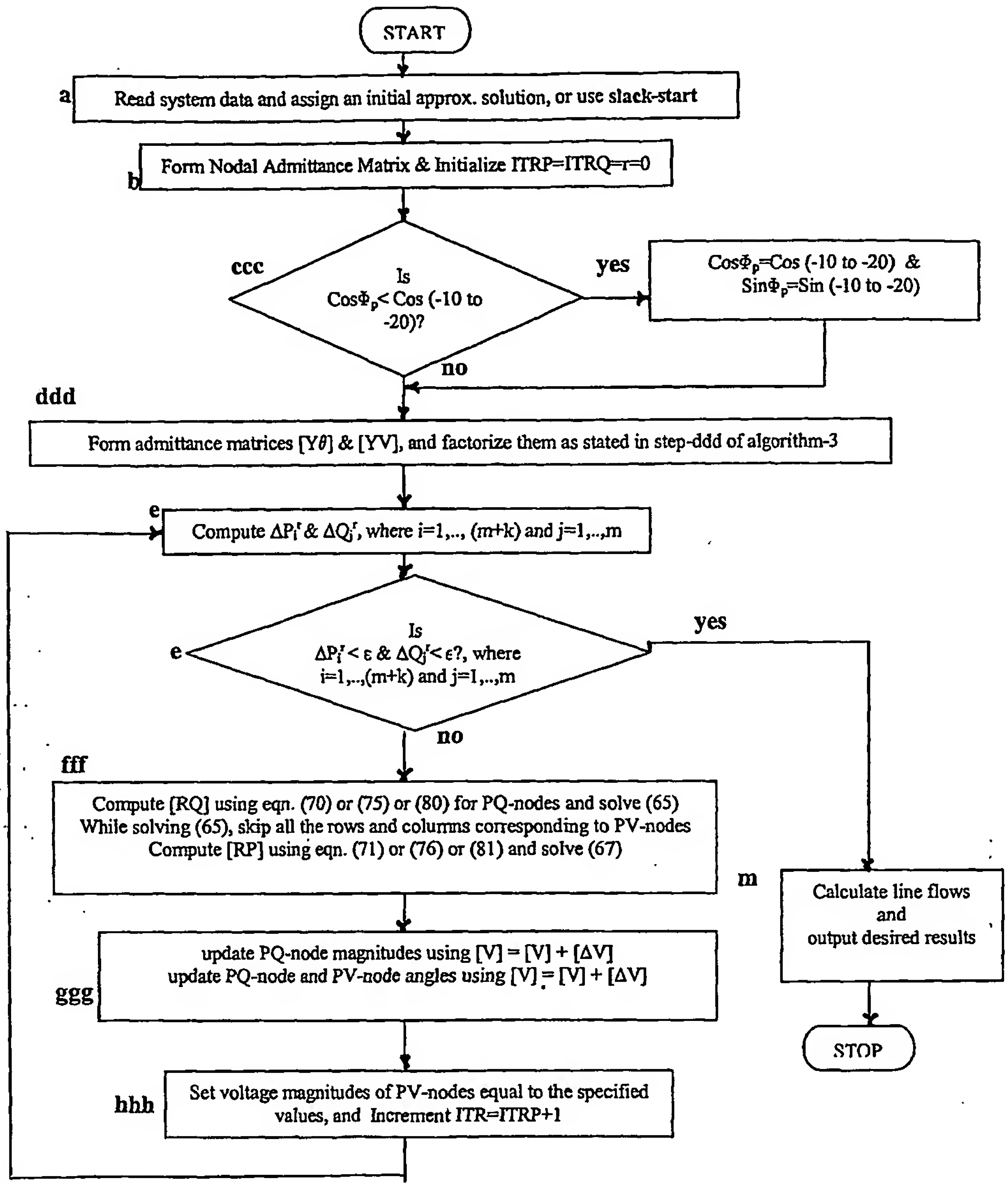

Fig.3: **Invention: Flow-chart of SSDL-BGX' solution algorithm-3**

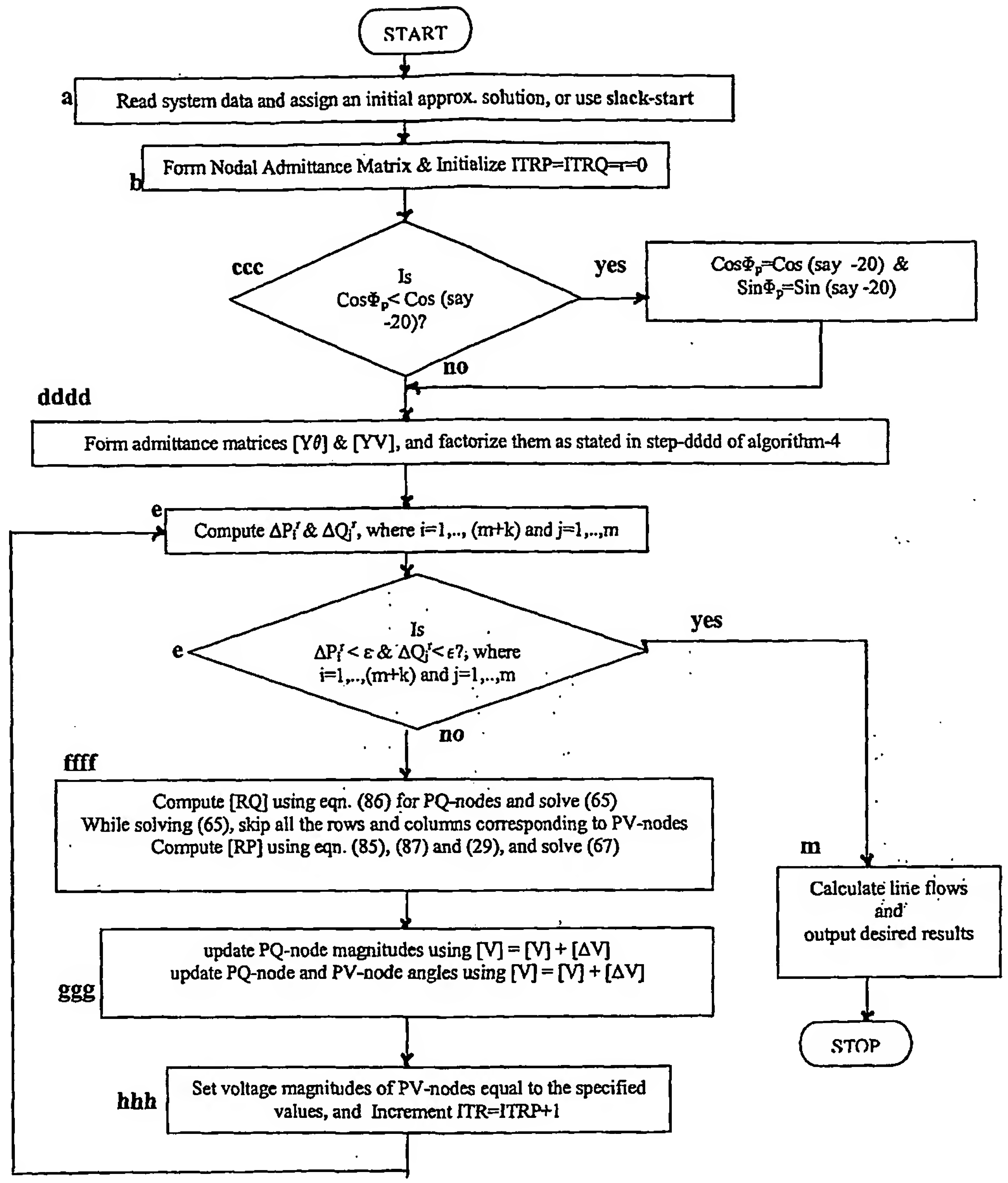

Fig.4: **Invention: Flow-chart of SSDL-X'G_{pv}X' solution algorithm-4**

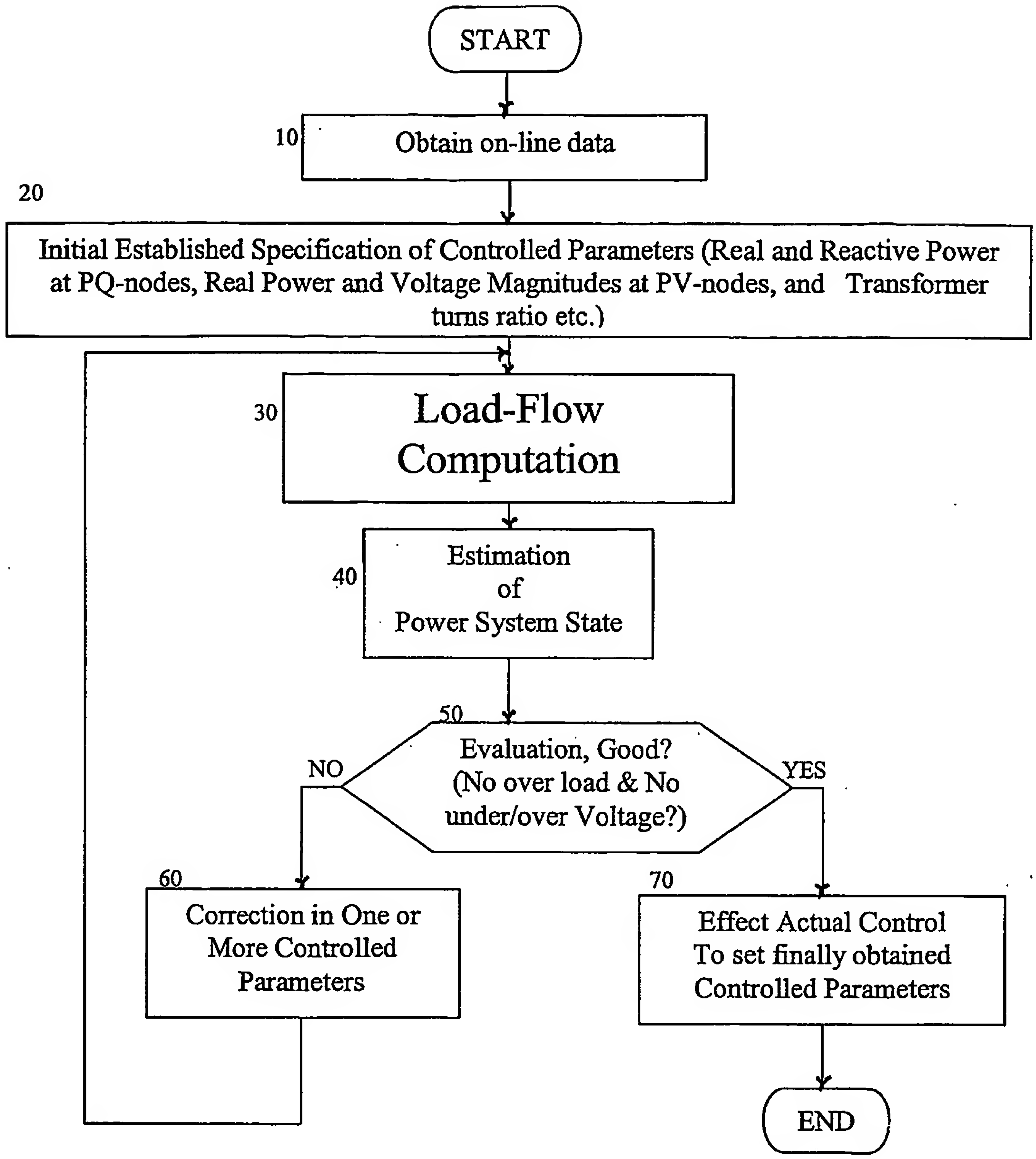

Fig. 5: **Load-Flow Computation in Security Control of Electrical Power System (PRIOR ART)**

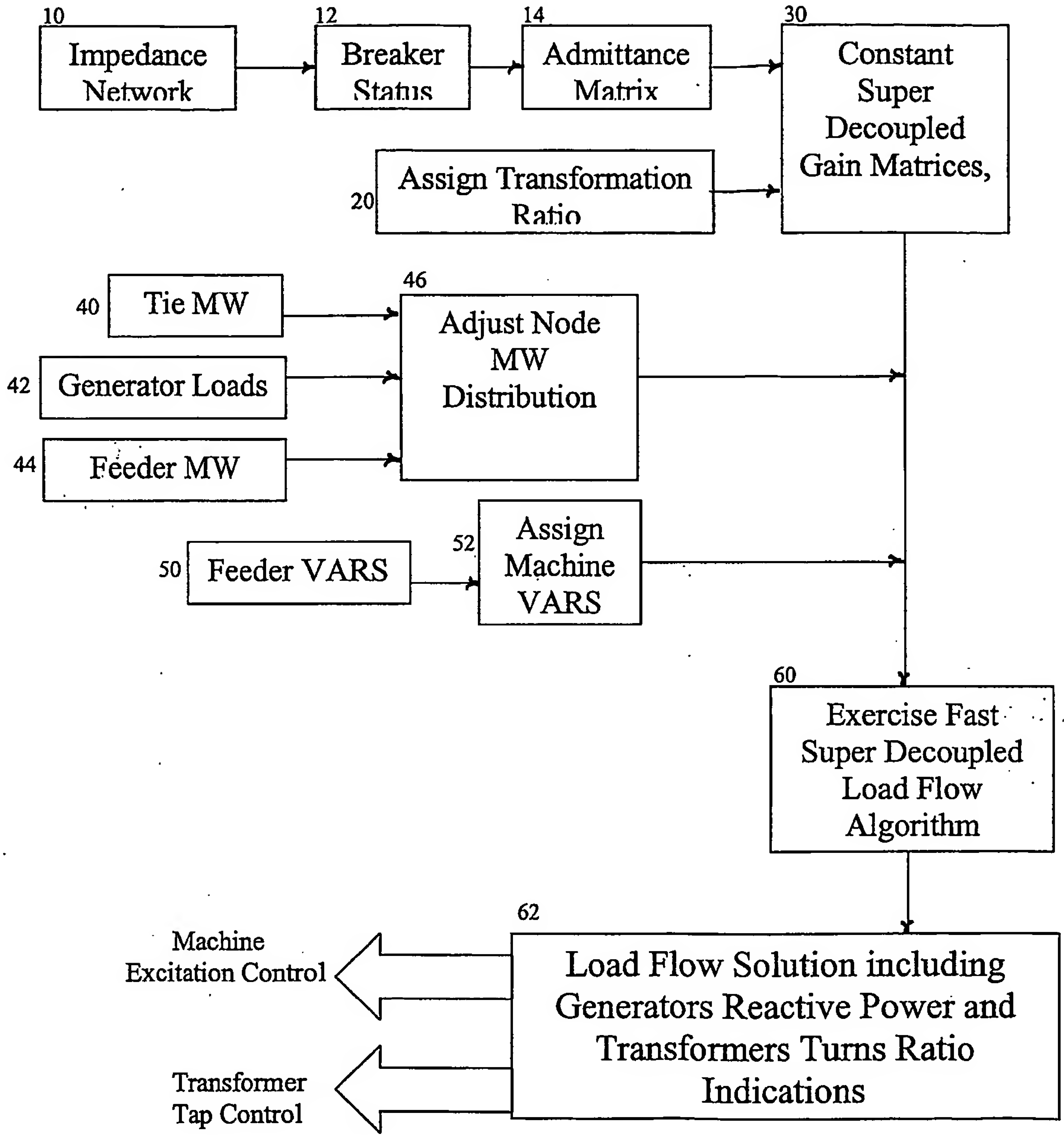

Fig. 6: Load-Flow Computation in Voltage Control of Electrical Power System (PRIOR ART)

DERWENT-ACC-NO: 2004-282949

DERWENT-WEEK: 200805

TITLE: Security e.g. voltage controlling method for industrial power network, involves computing variables indicating quotients of discrepancies from values of real and reactive power in each node and evaluating load flow computation

INVENTOR: PATEL S; PATEL S B

PATENT-ASSIGNEE: PATEL S[PATEI] , PATEL S B[PATEI]

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WO 2004023622 A2	March 18, 2004	EN
CA 2400580 A1	March 3, 2004	EN
AU 2003260221 A1	March 29, 2004	EN
AU 2003260221 A8	October 27, 2005	EN
EP 1661224 A2	May 31, 2006	EN
IN 200600436 P3	September 7, 2007	EN

DESIGNATED-STATES: AE AG AL AM AT AU AZ BA BB BG BR BY BZ CA CH CN CO CR CU CZ DE DK DM DZ EC EE ES FI GB GD GE GH GM HR HU ID IL IN IS JP KE KG KP KR KZ LC LK LR LS LT LU LV MA MD MG MK MN MW MX MZ NI NO NZ OM PG PH PL PT RO RU S C SD SE SG SK SL SY TJ TM TN TR TT TZ UA UG US UZ VC VN YU ZA ZM ZW AT BE BG CH CY CZ DE DK EA EE ES FI FR GB GH GM GR HU IE IT KE LS LU MC MW MZ NL OA PT RO SD SE SI SK SL SZ TR TZ UG ZM ZW AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LT LU L V MC MK NL PT RO SE SI SK TR

APPLICATION-DATA:

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WO2004023622A2	N/A	2003WO-CA01312	August 29, 2003
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IN 200600436P3	Based on	2006IN-MN00436	March 28, 2006

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CIPS	H02J3/06 20060101

ABSTRACTED-PUB-NO: WO 2004023622 A2

BASIC-ABSTRACT:

NOVELTY - The method involves computing variables indicating quotients of discrepancies from specified values of real and reactive power of each node. Load flow computation is evaluated and controlled parameters are corrected with correction values e.g. over load. The computing and evaluating steps are repeated again to effect a change in voltage and phases at node of a power system, when evaluating step finds a good power system.

DESCRIPTION - INDEPENDENT CLAIMS are also included for the following:

(a) a system of controlling generator and transformer voltages

(b) a method of controlling generator and transformer voltages.

USE - Used for controlling security in a utility/industrial power network.

ADVANTAGE - The method facilitates to perform load flow computation in real-time operation, thereby effectively providing security against overload and under load voltage for a power system.

DESCRIPTION OF DRAWING(S) - The drawing shows a flow chart of a super decoupled load flow computation method.

CHOSEN-DRAWING: Dwg.2/6

TITLE-TERMS: SECURE VOLTAGE CONTROL METHOD INDUSTRIAL POWER NETWORK COMPUTATION VARIABLE INDICATE QUOTIENT DISCREPANCY VALUE REAL REACT NODE EVALUATE LOAD FLOW

DERWENT-CLASS: T01 T06 X12 X13

EPI-CODES: T01-J07; T06-A06A; X12-C02B; X12-H01A1; X12-H01B; X12-H03; X13-G02X;

SECONDARY-ACC-NO:

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(54) Super Decoupled Loadflow Methods

(72) Patel, Sureshchandra B. - India ;

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(57) 1 Claim

5,102,5/41

Notice: This application is as filed and may therefore contain an incomplete specification.

2107388

SUPER DECOUPLED LOADFLOW METODS

ABSTRACT

The complete patent specification involves the invention of six super decoupled loadflow methods. The Fast Super Decoupled Loadflow (FSDL) method and two variants Transformed Fast Decoupled Loadflow (TFDLXB and TFDLBX) methods are known ones and included are their novel versions (NFSDL, NTFDLXB, NTFDLBX). These are the best versions of many simple variants with almost similar performance. These methods specifically involved the use of the following invented technics in the prior art method.

1. Gain matrices of all the six methods are different and they can be determined as described in the specification. Obviously the gain matrices of Pθ-subproblem can be defined unsymmetrical.

2. In all the six methods, rotation angles are restricted to the maximum value of -36 degrees from nonlinearity considerations.

3. Slack-start for any decoupled loadflow method for efficiency

4. Modification of real power mismatches at PV-nodes according to relations (12) and (15) of the specifications for the methods FSDL, TFDLXB, TFDLBX.

5. Computation of angle correction and updating for PV-nodes along with the voltage magnitude corrections at PQ-nodes for NFSDL, NTFDLXB and NTFDLBX methods. In the back-substitution part of the solution of this subproblem involving angle

corrections at PV-nodes and voltage magnitude corrections at PQ-nodes, skip factor elements corresponding to rows and columns of PV-nodes in the calculation of voltage magnitude corrections.

The specification deals only with unadjusted super decoupled loadflow solution methods and does not describe any applications. However the computer algorithms can be appropriately modified for adjustments and/or applications such as state estimation, contingency analysis etc.

Also described and claimed is the invention of two compact storage schemes for gain matrices ofthe FSDL method and two efficient procedures for node type switching implementations in the FSDL method.

Dated this 7 th day of November 1993

Signature of the inventor - S.B.Patel

2107388

THE CANADIAN PATENT ACT

THE COMPLETE SPECIFICATION

SUPER DECOUPLED LOADFLOW METHODS

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The following specification particularly describes and ascertains the nature of this invention and the manner in which it is to be performed.

This invention relates to the super decoupled methods of steady-state loadflow analysis of power system, and computer algorithms for carrying out these methods.

A computer algorithm processes raw information to yield useful information. A chemical process processes raw material to yield useful material. Useful information is well recognized as technological product in the modern age of information technology. Therefore, the computer algorithm like chemical process yields useful product and it is the useful art.

INTRODUCTION

Loadflow in power system studies is the most basic frequently performed steady state analysis of an electrical power network. The loadflows are performed in system planning, operational planning, and operation control. Of various methods proposed over the past four decades, Stott's Fast Decoupled Loadflow (FDL) [1] has gained wide acceptance both for off- and on- line applications. However, it is known to suffer poor convergence for systems having high R/X ratio branches (discussions in [1] & [2]).

Dy Liacco and Ramarao(discussion of [2]) as well as Deckmann et. al. [3] have developed circuit transformation schemes to avoid such difficulties. The two schemes however do not provide consistent improvement in convergence[4]. Also they are not general and are suitable where the system has a small number of troublesome R/X ratio branches.

A recently introduced super decoupled approach [5,6,7] is more general and reliable. Rotation operators applied to the complex node injections and the corresponding admittance values

that relate the above to the system state variables, transform the network equations such that branch admittances appear to be almost entirely reactive. Thus, better decoupling is realized. However, the super decoupled algorithms are not efficient and are not very convenient in contingency analysis. A recent modification to the FDL method for networks with high R/X ratio branches [4] is in fact variation of the super decoupled approach with a weakness that it takes higher number of iterations for normal cases.

General-purpose version of the Fast Decoupled Loadflow (GFDL) method[8] proposes simple modifications to the classical FDL method. The convergence is much improved in the presence of large R/X ratio lines. The two versions of FDL method are put in a better theoretical framework by Monticelli et. al.[9]. The GFDL method is nothing but an experimental investigation of the original observation made about the behaviour of the FDL method by this inventor as back as 1985 in an unaccepted research paper communicated to IEEE(New York).

The critically coupled loadflow methods are based on the use of the overlap update rule [10]. The disadvantage of the methods is that they involve the solution of a larger number of equations at each iteration. Moreover the tests conducted for the paper[10] avoided the increase of R/X ratio of branches connected to the PV-nodes. Therefore, conclusions of the paper are not based on exhautive testing. Test show that the invented six versions are the best loadflow methods. However, simply modified versions including hybrids of the six invented methods can also have closely similar performance for any given system.

The latest Novel Decoupled Loadflow Method[11] can simply be derived from published[12] and lately claimed invetion of this patent specification. In fact the idea involved in the method of [11] was revealed by this inventor in extensive communication for about four years with Institution of Electrical Engineers of England. Also the idea was investigated along with the modification of the real power mismatches at PV-nodes and only the best method was reported in reference [12]. Moreover the unsymmetrical gain matrix definition for the Pθsubproblem is obvious from the definition of the factor (K) used to modify real power mismatches of the PV-nodes[12]. However the method of [11] is not reliable for systems having PV-nodes and it has no flexibility of tuning rotation angle as was originally known to this inventor. Possibly this may be the reason that the author of [11] did not comapre his method with the Fast Super Decoupled Loadflow[12] and Transformation based Fast Decoupled Loadflow[13] methods.

Keywords : Power systems, Loadflow, Matrices, solution of simultaneous equations.

The invention will now be described, wherein the following symbols are used :

$\bar{Y}_{pq} = G_{pq} + jB_{pq}$: (p-q)-th element of nodal admittance matrix formed excluding shunts

$\bar{y}_p = g_p + jb_p$: total shunt admittance at node p

$\bar{V}_p = e_p + jf_p = V_p \angle \theta_p$: complex voltage at node p

$\Delta\theta_p$, ΔV_p : voltage angle, magnitude corrections

Δe_p, Δf_p	:	real, imeginary component corrections of voltage
$P_p + jQ_p$	:	net nodal injected power calculated
$\Delta P_p + j\,\Delta Q_p$	:	nodal power residue (mismatch)
$RP_p + jRQ_p$	:	modified nodal power residue
m	:	number of PQ-nodes
k	:	number of PV-nodes
n=m+k+1	:	total number of system nodes
q>p	:	q is the node adjacent to node p excluding the case q = p
[ ]	:	indicates enclosed variables to be vector or matrix

SUPER DECOUPLED LOADFLOW (SDL) METHOD (The prior art)

There are two versions of the Super Decoupled Loadflow method. These are based on the XB- and BX- versions of the Fast Decoupled Loadflow (FDL) method. The one based on the XB-version was developed in 1985 [7] and the other based on the BX-version is obvious from the BX-version of the FDL method developed in 1989 [8]. These methods involve the iterative solution of system of equations (1) and (2). Unlike FDL model the gain matrices in its, transformed version are unsymmetrical because mostly different rotations are required to be applied at the terminal nodes of a branch. Symmetrical gain matrices can be obtained by the Haley and Ayres technique [7] of applying average of the rotations at the terminal nodes of a branch to the branch admittance (appendix).

SDL based on the XB-version of the FDL (SDLXB)

The SDLXB-version is described by the following equations (1) to (10).

$$[RP] = [Y'] [\Delta\theta] \quad (1)$$

$$[RQ] = [Y''] [\Delta V] \quad (2)$$

Wherein each element of [RP] and [RQ] at PQ-nodes are given by (3) and (4) respectively. Whereas an element of [RP] at PV-nodes is given by (5).

$$RP_p = (\Delta P_p \cos\phi_p + \Delta Q_p \sin\phi_p)/V_p \quad (3)$$

$$RQ_p = (-\Delta P_p \sin\phi_p + \Delta Q_p \cos\phi_p)/V_p \quad (4)$$

$$RP_p = \Delta P_p / V_p \quad (5)$$

Trigonometric functions in (3) and (4) and elements of [Y'] and [Y"] are given by (6), (7) and, (8), (9) and (10).

$$\cos\phi_p = -B_{pp} / \sqrt{G_{pp}^2 + B_{pp}^2} \quad (6)$$

$$\sin\phi_p = -G_{pp} / \sqrt{G_{pp}^2 + B_{pp}^2} \quad (7)$$

$$Y'_{pq} = -1 / \tilde{X}_{pq} \quad \text{and} \quad Y''_{pq} = -\tilde{B}_{pq} \quad (8)$$

$$Y'_{pp} = \sum_{q \to p} -Y'_{pq} \quad \text{and} \quad Y''_{pq} = -2b'_p + \sum_{q \to p} -Y''_{pq} \quad (9)$$

$$b'_p = b_p \cos\phi_p \quad \text{or} \quad = b_p \quad (10)$$

Where $\tilde{X}_{pq}$ is the transformed branch reactance defined in appendix by eqation (41) and $\tilde{B}_{pq}$ is the corresponding transformed element of the susceptance matrix.

SDL based on the BX-version of the FDL (SDLBX)

The SDLBX-version differs from the SDLXB-version only in relation (8) as given by relation (11). The SDLBX-version consists of relations (1) to (7), (11), (9) and (10).

$$Y'_{pq} = -\tilde{B}_{pq} \quad \text{and} \quad Y''_{pq} = -1 / \tilde{X}_{pq} \tag{11}$$

INVENTED SUPER DECOUPLED LOADFLOW METHODS

Six invented super decoupled loadflow models are described in this section. Fast Super Decoupled and two versions of the Transformed Fast Decoupled models are Known ones [12,13] and included are their novel versions.

Fast Super Decuopled Loadflow (FSDL)

The FSDL method involves the iterative solution of the system of equations (1) and (2). The model cosists of relations (1) to (4), (6), (7), (12) to (16), (9) and (10).

$$RP_p = \Delta P_p / (K_p V_p) \tag{12}$$

Elements of [Y'] and [Y"] and the multiplier K_p in (12) are given by :

$Y'_{pq} = -Y_{pq}$ for branch r/x ratio $\leqslant$ 2.0

$= -(B_{pq} + 0.9(Y_{pq} - B_{pq}))$ for branch r/x ratio > 2.0

$= ~~-Bpq~~\ B_{pq}$ for branches connected between two PV-nodes or a PV-node and the slack-node (13)

$Y''_{pq} = -Y_{pq}$ for branch r/x ratio $\leqslant$ 2.0

$= -(B_{pq} + 0.9(Y_{pq} - B_{pq}))$ for branch r/x ratio > 2.0 (14)

$$K_p = \text{Absolute } (B_{pp} / Y'_{pp}) \qquad (15)$$

$$KKp = \text{Absolute } (Y'pp/Y"pp) \qquad (16)$$

Branch admittance magnitude in (13) and (14) is of the same algebraic sign as its susceptance. Elements of the two gain matrices differ in that diagonal elements of [Y"] additionally contain the b' values given by equation (10) and in respect of elements corresponding to branches connected between two PV-nodes or a PV-node and the slack-node. The factor 0.9 in the relations (13) and (14) is tuned only for rotation limited to -36 degrees. With different Limiting Rotation Angle(LRA), it needs to be tuned again. In two simple variations of the FSDL method, one is to make $Y"_{pq} = Y'_{pq}$ and the other is to make $Y'_{pq} = Y"_{pq}$.

Transformation based Fast Decoupled Loadflow (TFDL)

The TFDL model is similar to the FSDL model. They differ only in the definition of the gain matrices.

The TFDL(XB-version) (TFDLXB) Loadflow

The TFDLXB-version consists of relations (1) to (4), (12), (15), (6), (7), (17), (18), (19), (9) and (10).

$$Y'pq = \begin{cases} -Bpq & \text{for branches connected between two PV-nodes or a PV-node and the slack-node} \\ -1 / \tilde{X}_{pq} & \text{for all other branches} \end{cases} \qquad (17)$$

$$Y"_{pq} = -\tilde{B}_{pq} \qquad (18)$$

$$KK_p = \text{Absolute } (Y'_{pp} / (\sum_{p \neq q} 1/ \tilde{X}_{pq})) \qquad (19)$$

The TFDL(BX-version) (TFDLBX) Loadflow

The TFDLBX-version consists of relations (1) to (4), (12), (15), (6), (7), (20), (21), (22), (9) and (10).

$$Y'_{pq} = \begin{cases} -B_{pq} & \text{for branches connected between two PV-nodes or a PV-node and the slack-node} \\ -\tilde{B}_{pq} & \text{for all other branches} \end{cases} \quad (20)$$

$$Y''_{pq} = -1 / \tilde{X}_{pq} \quad (21)$$

$$KK_p = \text{Absolute } (Y'_{pp} / (\sum_{q \to p} \tilde{B}_{pq})) \quad (22)$$

Where $\tilde{X}_{pq}$ is the transformed branch reactance defined in appendix by eqation (41) and $\tilde{B}_{pq}$ is the corresponding transformed element of the susceptance matrix.

The factor KK_p is to be multiplied to the real power mismatch at a PV-node switched to PQ-type in node type switching implementation. From general considerations, K_p and KK_p are restricted to the minimum value of 0.75 for FSDL, TFDLXB and TFDLBX methods. However they can be tuned for the best possible convergence for any given system.

In all the SDLXB, SDLBX, FSDL, TFDLXB and TFDLBX models [Y'] and [Y"] are real, sparse, symmetrical and built only from network elements. Since they are constant, they need to be factorized once only at the start of the solution. Equations (1) and (2) are to be solved repeatedly by forward and backward substitutions.

[Y'] and [Y"] are of the same dimensions (m+k)*(m+k) when only a row/column of the slack-node is excluded and both are triangularized using the same ordering regardless of the node-types. For a row/column corresponding to a PV-node excluded in [Y"], use a large diagonal to mask out the effects of the off-diagonal terms. When the node is switched to the PQ-state the row/column is reactivated by removing the large diagonal. This technique is especially useful in the treatment of PV-nodes in the matrix [Y"].

It is invented to make this technique efficient while solving (2) for ΔV by skipping all PV-nodes and factor elements with indices corresponding to PV-nodes. In other words efficiency can be realized by skipping operations on rows/columns corresponding to PV-nodes in the forward-backward solution of (2) for ΔV. This has been implemented and the time saving of about 4% of the total solution time (including input/output) could be realized in 14-14 iterations required to solve 118-node system with the uniform R-scale factor 4 applied. The time saving has been assessed on PC-XT. It should be noted that the same indexing and addressing information can be used for the storage of both the matrices as they are of the same dimensions and sparsity structure.

Novel Fast Super Decoupled Loadflow (NFSDL)

The NFSDL method involves the iterative solution of the following system of equations (23) and (24).

$$[RP] = [Y1]\,[\Delta\theta] \tag{23}$$

$$\begin{bmatrix} RQ(\text{PQ-nodes}) \\ RP(\text{PV-nodes}) \end{bmatrix} = \begin{bmatrix} Y2 \end{bmatrix} \begin{bmatrix} \Delta V(\text{PQ-nodes}) \\ \Delta\theta(\text{PV-nodes}) \end{bmatrix} \tag{24}$$

Wherein each element of [RP] and [RQ] at PQ-nodes are given by (3) and (4) respectively. Whereas an element of [RP] at PV-nodes is given by (5). In (24) PV-nodes are assumed to be grouped and numbered after all PQ-nodes.

Elements of [Y1] and [Y2] are given by :

$$Y'_{pq} = \begin{cases} -Y_{pq} & \text{for branch r/x ratio} \leq 2.0 \\ -(B_{pq} + 0.9(Y_{pq} - B_{pq})) & \text{for branch r/x ratio} > 2.0 \\ -Bpq & \text{for branches connected between two PV-nodes or a PV-node and the slack-node} \end{cases} \quad (25)$$

$$Y2pq = \begin{cases} Gpq & \text{for branches connected to a PQ-node and a PV-node} \\ -Y1pq & \text{for branches connecting two PQ-nodes} \\ Y1_{pq} & \text{for branches connecting two PV-nodes} \end{cases} \quad (26)$$

$$Y1_{pp} = \sum_{q \to p} -Y1_{pq} \quad (27)$$

$$Y2pp = \begin{cases} 2bp\text{-}Y1pp & \text{for PQ-nodes} \quad 2b'_p - Y1_{pp} \\ -B_{pp} & \text{for PV-nodes} \end{cases} \quad (28)$$

The NFSDL model consists of relations (23), (24), (3) to (7), (25) to (28), and (10). Branch admittance magnitude in (25) is of the same algebraic sign as its susceptance.

Novel Transformed Fast Decoupled Loadflow (NTFDL)

The NTFDL model is similar to the NFSDL model. They differ only in the defination of gain matrices.

The NTFDL(XB-version) (NTFDLXB) Loadflow

The NTFDLXB model consists of relations (23), (24), (3) to (7), (29) to (32), and (10).

$$Y1pq = \begin{cases} -Bpq & \text{for branches connected between two PV-nodes or a PV-node and the slack-node} \\ -1 / \tilde{X}_{pq} & \text{for all other branches} \end{cases} \tag{29}$$

$$Y2pq = \begin{cases} Gpq & \text{for branches connected to a PQ-node and a PV-node} \\ \tilde{B}_{pq} & \text{for branches connecting two PQ-nodes} \\ -B_{pq} & \text{for branches connecting two PV-nodes} \end{cases} \tag{30}$$

$$Y1_{pp} = \sum_{q \to p} -Y1_{pq} \tag{31}$$

$$Y2_{pp} = \begin{cases} 2b'_p+\tilde{B}_{pp} & \text{for PQ-nodes} \\ -B_{pp} & \text{for PV-nodes} \end{cases} \tag{32}$$

Where $\tilde{X}_{pq}$ is the transformed branch reactance defined in appendix by eqation (41) and $\tilde{B}_{pq}$ is the corresponding transformed element of the susceptance matrix.

The NTFDL(BX-version) (NTFDLBX) Loadflow

The NTFDLBX model consists of relations (23), (24), (3) to (7), (33) to (36), and (10).

$$Y1pq = \begin{cases} -Bpq & \text{for branches connected between two PV-nodes or a PV-node and the slack-node} \\ -\tilde{B}_{pq} & \text{for all other branches} \end{cases} \tag{33}$$

$$Y2pq = \begin{cases} Gpq & \text{for branches connected to a PQ-node and a PV-node} \\ 1/\tilde{X}_{pq} & \text{for branches connecting two PQ-nodes} \\ -B_{pq} & \text{for branches connecting two PV-nodes} \end{cases} \quad (34)$$

$$Y1_{pp} = \sum_{q \to p} -Y1_{pq} \quad (35)$$

$$Y2_{pp} = \begin{cases} 2b'_p + \sum_{q \to p} -1/\tilde{X}_{pq} \quad \text{or} \quad = 2b'_p + 1/\tilde{X}_{pp} & \text{for PQ-nodes} \\ -B_{pp} & \text{for PV-nodes} \end{cases} \quad (36)$$

In the NFSDL NTFDLXB and NTFDLBX methods [Y1] and [Y2] are real, sparse, symmetrical and built only from network elements. Since they are constant, they need to be factorized once only at the start of the solution. Equations (23) and (24) are to be solved repeatedly by forward and backward substitutions.

[Y1] and [Y2] are of the same dimensions (m+k)*(m+k) when only a row/column of the slack-node is excluded and both are triangularized using the same ordering regardless of the node-types. It should be noted that the same indexing and addressing information can be used for the storage of both the matrices as they are of the same dimensions and sparsity structure. Unlike [Y"], It is to be noted that all the PV-nodes are also active in [Y2]. Therefore, the novel methods would pose a difficult problem of node-type switching.

ϕ_p is restricted to the maximum of -36 degrees from nonlinearity considerations for FSDL, TFDLXB, TFDLBX, NFSDL, NTFDLXB and NTFDLBX methods. However it can be tuned for the best possible convergence for any given system and it can also be vertually unrstricted -90 degrees.

Iteration Scheme

The basic iterative scheme for solving the proposed models is to solve for [$\Delta\theta$] to update [θ] and then solve (2) or (24). This is the block Gauss-Seidel approach. The scheme is block-successive which imparts increased stability to the solution process. This in turn improves convergence and increases reliability. Cycling behaviour in the iterative process of the standared iteration scheme of [1] can be avoided by simply using different convergence tolerances for the real and reactive power mismatches as suggested in [9]. The cycling behaviour and its remedy as above were originally observed by this inventor as back as in 1985 in an unaccepted paper submitted to IEEE and prepared from research conducted at the university of Roorkee. However, algorithms are given for strictly successive iteration scheme of [8].

APPENDIX

Transformation of Branch Admittance

The branch admittance transforamation for symmetrical gain matrices of the TFDLXB, TFDLBX, NTFDLXB and NTFDLBX methods is given by the following steps :

1. Compute : $\phi_{pp} = \arctan(G_{pp}/B_{pp})$ and

$$\phi_{qq} = \arctan(G_{qq}/B_{qq}) \tag{37}$$

2. Compute the average of rotations at the terminal nodes (p and q) of a branch :

$$\phi_{av} = (\phi_{pp} + \phi_{qq}) / 2 \tag{38}$$

3. Compare ϕ_{av} with the Limiting Rotation Angle (LRA) and let ϕ_{av} to be the smaller of the two :

$$\phi_{av} = \text{minimum}\ (\phi_{av}\ ,\ \text{LRA}) \tag{39}$$

4. Compute transformed pq-th element of the admittance matrix :

$$G_{pq} + jB_{pq} = (\text{Cos}\phi_{av} + j\text{Sin}\phi_{av})\ (G_{pq} + jB_{pq}) \tag{40}$$

5. Note that the transformed branch reactance is :

$$X_{pq} = B_{pq}\ /\ (G_{pq}^{2} + B_{pq}^{2}) \tag{41}$$

and similarly

$$X_{pp} = B_{pp}\ /\ (G_{pp}^{2} + B_{pp}^{2}) \tag{42}$$

ALGORITHM-1 (The prior art)

Super Decoupled Loadflow Algorithms (solution Steps)

Strictly Successive (1θ, 1V) Iterative Scheme :

(a) Read system data and assign an initial approximate solution. If better solution estimate is not available, set specified voltage magnitudes at PV-nodes and 1.0 p.u. voltage magnitudes at PQ-nodes. Set all the node angles equal to that of the Slack-node angle. This is referred to as the flat-start [1].

(b) Initialize iteration counts ITRP=ITRQ=r=0

(c) Form nodal admittance matrix

(d) Form (m+k) by (m+k) size matrices [Y′] and [Y″] of (1) and (2) respectively each in a compact storage exploiting sparsity.

(i) In case of SDLXB-method, the matrices are formed usig relations (8), (9) and (10).

(ii) In case of SDLBX-method, the matrices are formed using relations (11), (9) and (10).

(e) In [Y″] matrix,replace diagonal elements corresponding to PV -nodes by very large value (say 10.0**10).In case [Y″] is of dimension (m by m),this is not reqired to be performed. Factorize [Y′] and [Y″] using the same ordering regardless of the node-types. In case [Y″] is of dimension (m by m), it is factorized using different ordering than that of [Y′].

(f) Compute residues ΔP^r (PQ- and PV-nodes) and ΔQ^r (at PQ-nodes only). If all are less than the tolerance (ε), proceed to step (n). Otherwise follow the next step.

(g) Compute the vector of modified residues [RP] using (3) for PQ-nodes and using (5) for PV-nodes.

(h) Solve (1) for voltage angle corrections and update voltage angles using eqn. (43).

(i) Increament the iteration count ITRP=ITRP+1 and r=(ITRP+ITRQ)/2.

(j) Compute residues ΔP^r (PQ- and PV-nodes) and ΔQ^r (at PQ-nodes only). If all are less than the tolerance (ε), proceed to step (n). Otherwise follow the next step.

(k) Compute the vector of modified residues [RQ] using (4) for PQ-nodes only.

(l) Solve (2) for voltage magnitude corrections and update voltage magnitudes of PQ-nodes only using eqn.(44).

(m) Increament the iteration count ITRQ=ITRQ+1 and r=(ITRP+ITRQ)/2. Proceed to step (f)

(n) Calculate line flows and output the desired results.

The SDLXB and SDLBX algorithms differ only in step-d defining gain matrices in the above solution steps. Fig.1 is the flowchart of algorithm-1.

ALGORITHM-2 (containing invented steps)

Fast Super Decoupled Loadflow Algorithms (solution Steps)
Strictly Successive (1θ, 1V) Iterative Scheme |

(a) Read system data and assign an initial approximate solution. If better solution estimate is not available, set all the nodes voltage magnitudes and angles equal to those of the Slack-node. This is referred to as the slack-start.

(b) Initialize iteration counts ITRP=ITRQ=r=0

(c) Form nodal admittance matrix

(d) Form (m+k) by (m+k) size matrices [Y′] and [Y″] of (1) and (2) respectively each in a compact storage exploiting sparsity.

(i) In case of FSDL-method, the matrices are formed using relations (13), (14), (9) and (10).

(ii) In case of TFDLXB-method, the matrices are formed usig relations (17), (18), (9) and (10).

(iii) In case of TFDLBX-method, the matrices are formed using relations (20), (21), (9) and (10).

(e) In [Y"] matrix,replace diagonal elements corresponding to PV -nodes by very large value (say 10.0**10).In case [Y"] is of dimension (m by m), this is not reqired to be done. Factorize [Y'] and [Y"] using the same ordering regardless of the node-types. In case [Y"] is of dimension (m by m), it is factorized using different ordering than that of [Y'].

(f) Compute residues ΔP^r (PQ- and PV-nodes) and ΔQ^r (at PQ-nodes only). If all are less than the tolerance (ε), proceed to step (n). Otherwise follow the next step.

(g) Compute the vector of modified residues [RP] using (3) for PQ-nodes and using (12) and (15) for PV-nodes. In (3) ϕ_p is restricted to the maximum of -36 degrees (or any other angle) from nonlinearity considerations. It can be even unrestricted for any given system (-90 degree).

(h) Solve (1) for voltage angle corrections and update voltage angles using relation (43).

$$\theta_p^r = \theta_p^{(r-1)} + \Delta\theta_p^r \tag{43}$$

(i) Set the voltage magnitudes of PV-nodes equal to the specified values. This is required to be done only in the first iteration when slack-start is used. Increament the iteration count ITRP=ITRP+1 and r=(ITRP+ITRQ)/2.

(j) Compute residues ΔP^r (PQ- and PV-nodes) and ΔQ^r (at PQ-nodes only). If all are less than the tolerance (ε), proceed to step (n). Otherwise follow the next step.

(k) Compute the vector of modified residues [RQ] using (4). In (4) ϕ_p is restricted to the maximum of -36 degrees (or any other angle) from nonlinearity considerations. It can be even unrestricted for any given system (-90 degree).

(l) Solve (2) for voltage magnitude corrections and update voltage magnitudes of PQ-nodes only as given by relation (44). While solving (2), skip all the rows and columns corresponding to PV-nodes to increase the efficiency.

$$V_p^r = V_p^{(r-1)} + \Delta V_p^r \tag{44}$$

(m) Increament the iteration count ITRQ=ITRQ+1 and r=(ITRP+ITRQ)/2. Proceed to step (f)

(n) Calculate line flows and output the desired results.

All the above steps can also be the parts of the classical (1θ, 1V) iteration scheme of reference [1]. This algorithm is for solving loadflow problem formulated in polar coordinates. The solution of the loadflow model formulated in rectangular coordinates also involve similar steps with minor modifications. Gain matrices of the invented methods are the same for both polar- and rectangular-coordinate formulations of the loadflow problem. Fig.2 is the flowchart of algorithm-2. The FSDL-method, TFDLXB-method and TFDLBX-method differ only in step-d defining gain matrices in the above algorithm-2.

ALGORITHM-3 (invclude invented steps)

Novel Fast Super Decoupled Loadflow Algorithms (solution Steps)

Strictly Successive (1θ, 1V) Iterative Scheme |

(a) Assign an initial approximate solution. If better solution estimate is not available, set all the nodes voltage magnitudes and angles equal to those of the Slack-node. This is referred to as the slack-start.

(e) Initialize iteration counts ITRP=ITRQ=r=0

(c) Form nodal admittance matrix

(d) Form (m+k) by (m+k) size matrices [Y1] and [Y2] of (23) and (24) respectively each in a compact storage exploiting sparsity.

(iv) In case of NFSDL-method, the matrices are formed using relations (25) to (28), and (10).

(v) In case of NTFDLXB-method, the matrices are formed using relations (29) to (32) and (10).

(vi) In case of NTFDLBX-method, the matrices are formed using relations (33) to (36) and (10).

(e) Factorize [Y1] and [Y2] using the same ordering regardless of the node-types.

(f) Compute residues ΔP^{r} (PQ- and PV-nodes) and ΔQ^{r} (at PQ-nodes only). If all are less than the tolerance (ϵ), proceed to step (n). Otherwise follow the next step.

(g) Compute the vector of modified residues [RP] using (3) for PQ-nodes and using (5) for PV-nodes. In (3) ϕ_p is restricted to the maximum of -36 degrees (or any other angle) from nonlinearity considerations. It can be even unrestricted for any given system (-90 degrees).

(h) Solve (23) for voltage angle corrections and update voltage angles using relation (43).

(i) Set the voltage magnitudes of PV-nodes equal to the specified values. This is required to be done only in the first iteration when slack-start is used. Increament the iteration count ITRP=ITRP+1 and r=(ITRP+ITRQ)/2.

(j) Compute residues ΔP^r (PQ- and PV-nodes) and ΔQ^r (at PQ-nodes only). If all are less than the tolerance (ϵ), proceed to step (n). Otherwise follow the next step.

(k) Compute the vector of modified residues [RQ] using (4) for PQ-nodes. Compute [RP] for PV-nodes using (5). In (4) ϕ_p is restricted to the maximum value of -36 degrees (or any other angle) from nonlinearity considerations. It can be even unrestricted for any given system (-90 degrees).

(l) Solve (24) for voltage magnitude corrections at PQ-nodes and voltage angle corrections at PV-nodes. Update voltage magnitudes of PQ-nodes using relation (44) and angles of PV-nodes using relation (43). In the back substitution part of the solution of (24), skip all the PV-nodes in the calculation of voltage-magnitude corrections of PQ-nodes.

(m) Increament the iteration count ITRQ=ITRQ+1 and r=(ITRP+ITRQ)/2. Proceed to step (f)

(n) Calculate line flows and output the desired results.

All the above steps can also be the parts of the classical (1θ, 1V) iteration scheme of reference [1]. This algorithm is for solving loadflow problem formulated in polar coordinates. The solution of the loadflow model formulated in rectangular coordinates also involve similar steps with minor modifications. Gain matrices of the invented methods are the same for both polar- and rectangular-coordinate formulations of the loadflow problem. The NFSDL-method, NTFDLXB-method and NTFDLBX-method differ only in step-d defining gain matrices in the above algorithm-3. Fig.3 is the flow-chart of algorithm-3.

ALGORITHMS using GLOBAL CORRECTIONS

The algorithms-1, -2 and -3 of above involve increamental(or local) corrections. All the above algorithms can be organised to produce corrections to the initial estimate solution. It involves storage of the vectors of modified residues and replacing the relations (3),(4),(5),(12),(43) and (44) respectivly by (45),(46),(47), (48),(49) and (50). Superscript '0' in relations (49) and (50) indicates the initial solution estimate.

$$RP_p^r = (\Delta P_p^r \, Cos\phi_p + \Delta Q_p^r \, Sin\phi_p)/V_p^r + RP_p^{(r-1)} \tag{45}$$

$$RQ_p^r = (-\Delta P_p^r \, Sin\phi_p + \Delta Q_p^r \, Cos\phi_p)/V_p^r + RQ_p^{(r-1)} \tag{46}$$

$$RP_p^r = \Delta P_p^r / V_p^r + RP_p^{(r-1)} \qquad (47)$$

$$RP_p^r = \Delta P_p^r / (K_p * V_p^r) + RP_p^{(r-1)} \qquad (48)$$

$$\theta_p^r = \theta_p^0 + \Delta\theta_p^r \qquad (49)$$

$$V_p^r = V_p^0 + \Delta V_p^r \qquad (50)$$

RECTANGULAR COORDINATE FORMULATIONS OF THE INVENTED LOADFLOW METHODS

This involves following changes in the equations describing the loadflow models formulated in polar coordinates.

(i) Replace θ and $\Delta\theta$ respectively by f and Δf in equations (1), (23), (24), (43) and (49).

(ii) Replace V and ΔV respectively by e and Δe in equations (2), (24), (44) and (50).

(iii) Replace V_p by e_p or e_s in equations (3), (4), (5), (12), (45), (46), (47) and (48). The subscript 's' indicates the Slack-node variable.

(iv) After calculation of corrections to the imeginary part of complex voltage (Δf) of PV-nodes and updating the imaginary component (f) of PV-nodes, calculate real component by :

$$e_p = V^2_{p(specified)} - f^2_p \qquad (51)$$

COMPACT STORAGE SCHEMES FOR GAIN MATRICES OF THE FSDL METHOD

Two compact matrix storage schemes for gain matrices of the FSDL method are described in the following.

(1) When network shunts are ignored (FK=0.0), [Y"] becomes the submatrix of [Y']. In this scheme, [Y'] is factorized using optimal ordering regardless of node-types along with the following procedure :

1. Identify PQ-nodes in the composite path of all PV-nodes.

2. Reload and refactor all row/columns of these PQ-nodes using partial refactorization method PR1 of [13]. Store these factors separately.

3. When solving for ΔV using factors of [Y'] :
   (i) all PV-nodes and factor elements with indices corresponding to PV-nodes are skipped. Zeroing of reactive power mismatches at PV-nodes is not required.
   (ii) for PQ-nodes of the path, separately stored factors as in step-2 above are used along with the other factors of [Y'] in forward-backward operations.

The above procedure is implemented. For 118-node system, there are only 18 PQ-nodes in the composite path of all 53 PV-nodes. Each of the gain matrices [Y'] and [Y"] is having 117-row/columns for 118-node system, and the total of 234-row/columns are to be factorized and stored for conventional 2-matrix solution. Threfore the proposed second scheme can be said to be saving 42% (99/234=0.42) of the factorization effort and core memory. This saving rises to the maximum 50% for systems without PV-nodes.

(2) When network shunts are ignored (FK=0.0), [Y"] becomes the submatrix of [Y′]. In the single matrix version of the FSDL method only [Y′] is factorized and stored. This is achieved exactly by placing PV-nodes after all PQ-nodes and by allowing optimal ordering only within each group. While solving (2) for ΔV, all PV-nodes and factor elements with indices corresponding to PV-nodes are skipped. Zeroing of reactive power mismatch at PV-nodes is not required. Apperantly, 50% reduction in the matrix storage is achieved in the absence of PV-nodes.

PV-node Q-limit Adjustment for the FSDL method

When the power flow solution is moderately converged, any Q-limit violations should be corrected. Any violated PV-node is converted to the PQ-type with the rective generation set at the limiting value. The voltage of the converted node is subsequently compared to the scheduled value and the node is reconverted to the PV-type, if any of the back-off conditions are satisfied.

The conventional node-type switching approach is more suitable for the handling of the PV-node Q-limiting. The switching of node-types involves the insertion/delation of eqalities into/from (2). This can be achieved efficiently by partial matrix refactorization and factor updating methods. Partial Refactorization Method-1 (PR1)[13] can be used to update [Y"] in order to account for changes in the node status (regulated or nonregulated). The efficiency of PR1 is inversely proportional to the number of node status changes. Two efficient techniques of the node-type switching are described in the following.

(1) When network shunts are ignored (FK=0.0) or accounted by alternative ways, a reactivated row/column by the removal of the large diagonal corresponding to a PV-node in [Y"] is identical to that in [Y']. It is this feature of the FSDL method exploited to enhance the efficiency of the node type switching using the following procedure. This is convenient with the simple variant of the FSDL method mentioned before.

1. find the composite path of PV-nodes switched to PQ-type

2. find the composite path of the rest of the PV-nodes

3. refactor only rows/columns of [Y"] that constitute common path of steps 1 and 2. The factored rows/columns of [Y'] in the uncommon path of step 1 can be used for the partial refactorization of [Y"]

4. while solving (2), use factors from [Y'] in the uncommon part of the path of step 1 along with other factos of [Y"].

When all the PV-nodes of the system are switched to PQ-type, [Y'] is used for solving (2) and no partial refactorization in [Y"] is required. Also when common path to be determined in step-3 does not exist, partial refactorization is not required.

(2) The compact storage scheme (1) for the FSDL method described above inherently provides for efficient implimentation of node-type switching used for PV-node Q-limit adjustment. The procedure constitutes the following steps.

1. PQ-nodes in the composite path of all PV-nodes are known and their rows/columns are factored and stored separately from those of [Y'] for unadjusted solution.

2. Identify PQ-nodes in the composite path of current PV-nodes.

3. Identify PQ-nodes which are not common in steps 1 and 2.

4. Carry out Reverse Correction Partial Matrix Refactorization along the composite path of PQ-nodes of step-3 on separately stored factors of step-1. Use large diagonals in rows/columns of PQ-nodes of step-3.

If no PQ-node is identified in step-3, Reverse correction Partial matrix refactorization of step-4 is not required to be performed.

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I CLAIM :

(a) To have invented three Super Decoupled Loadflow methods (FSDL, TFDLXB and TFDLBX) both in Polar coordinate and Rectangular coordinates formulations, their Novel versions (NFSDL, NTFDLXB and NTFDLBX), and their all possible hybrid cobinations. Also I claim to have invented the technique of producing Global corrections as given by relations (45) to (50).

(b) Specifically the invention involves the use of the following seven(7) items in the methods of (a):

(i) the definitions of the gain matrices of the six-methods of (a) corresponding to steps-d in algorithm-2 and algorithm-3, for both polar and rectangular formulations of the loadflow problem. Though explicit definitions of unsymmetrical gain matrices of Pθ-subproblem are not given, they are obvious for all the six methods and they are also claimed by this inventor as simple modifications.

(ii) restriction of rotation angle ϕ_p to the maximum of -36 degrees (any other angle) in relations (3),(4),(45) and (46) from nonlinearity considerations, for both polar and rectangular coordinate formulations of the loadflow problem.

(iii) modification of real power mismatch at PV-nodes according to relations (12) and (15) in FSDL, TFDLXB and TFDLBX-

methods formulated in both polar and rctangulr coordinates. This in general is the technique to modify the known vector to ensure the coefficient/gain matrix symmetrical. It can be used in all possible computer algorithms (including all other approaches of the formulation of the loadflow problem) and real-time/on-line/off-line applications.

(iv) computation of angle corrections and updating for PV-nodes along with the Voltage magnitude corrections while solving equation (24) for NFSDL, NTFDLXB and NTFDLBX methods. In the back-substitution part of the solution of (24), I claim to have invented the technique to skip all the rows and columns corresponding to PV-nodes for calculation of voltage magnitude corrections of PQ-nodes. This also applies when the novel methods are formulated in rectangular coordinates.

(v) the Slack-start procedure for all the decoupled loadflow methods and in particular for the six methods of (a) above.

(vi) similar decoupled methods as of (a) can also be used for solving simultaneous equations appearing in other areas of analysis, operation and control.

(vii) The six invented methods of unadjusted loadflow solution can be used for adjusted solution by adding some more steps in the algorithms, state estimation, contingency analysis and in variety of advanced power network analysis and control.

(c) Also I claim to have invented two compact storage schemes for gain matrices of the FSDL method and two efficient procedures of the node-type switching implementations for the FSDL method as described in the above.

Dated this 7 th day of november 1993.

S.B.Patel

Signature of the Inventor S.B.Patel

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No. :

No. of Sheets : 3
Sheet No. : 1

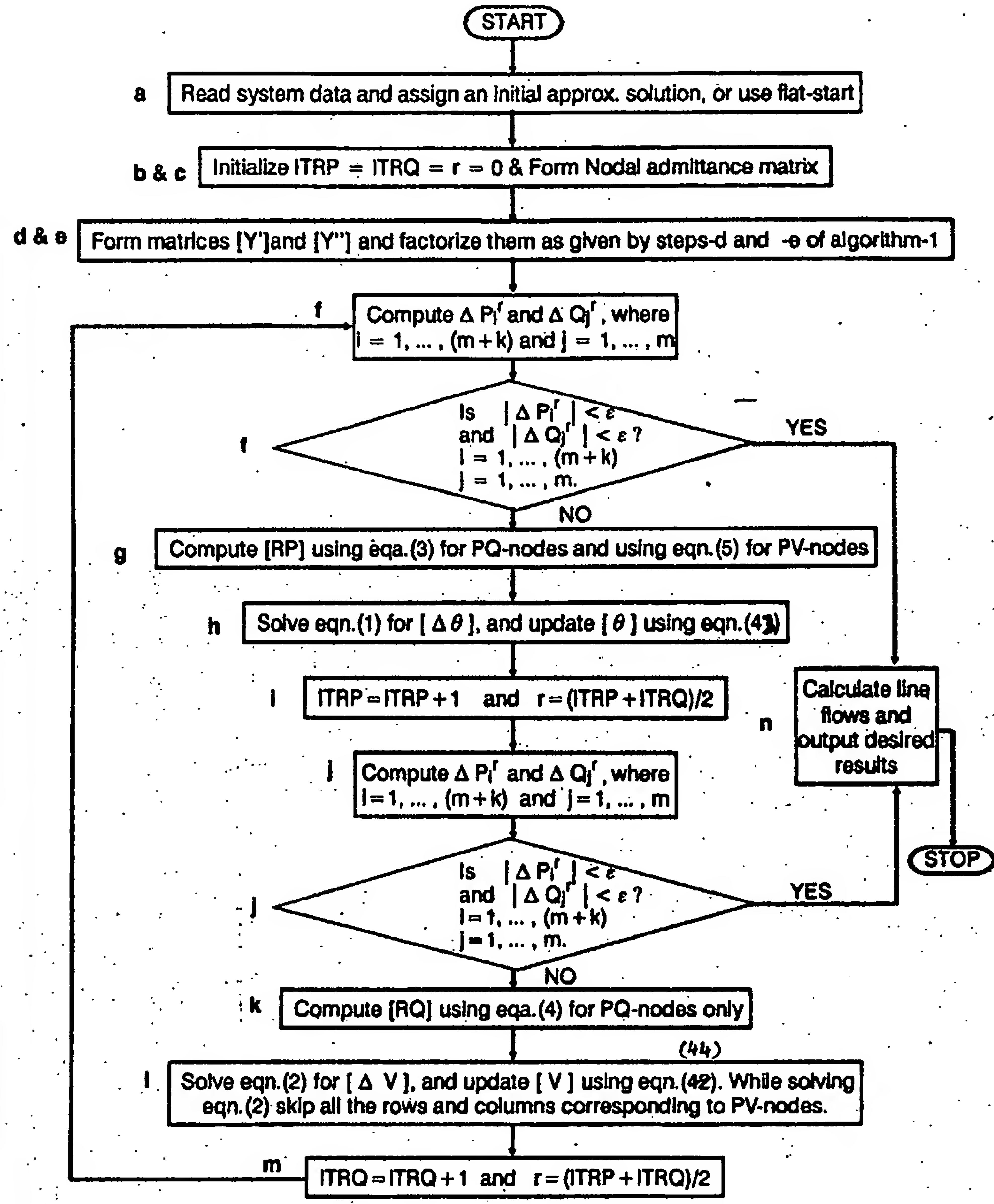

Fig. 1 Flow-chart of unadjusted load flow solution algorithm-1.
It is the same for SDLXB and SDLBX methods. (flow-chart of the prior art)

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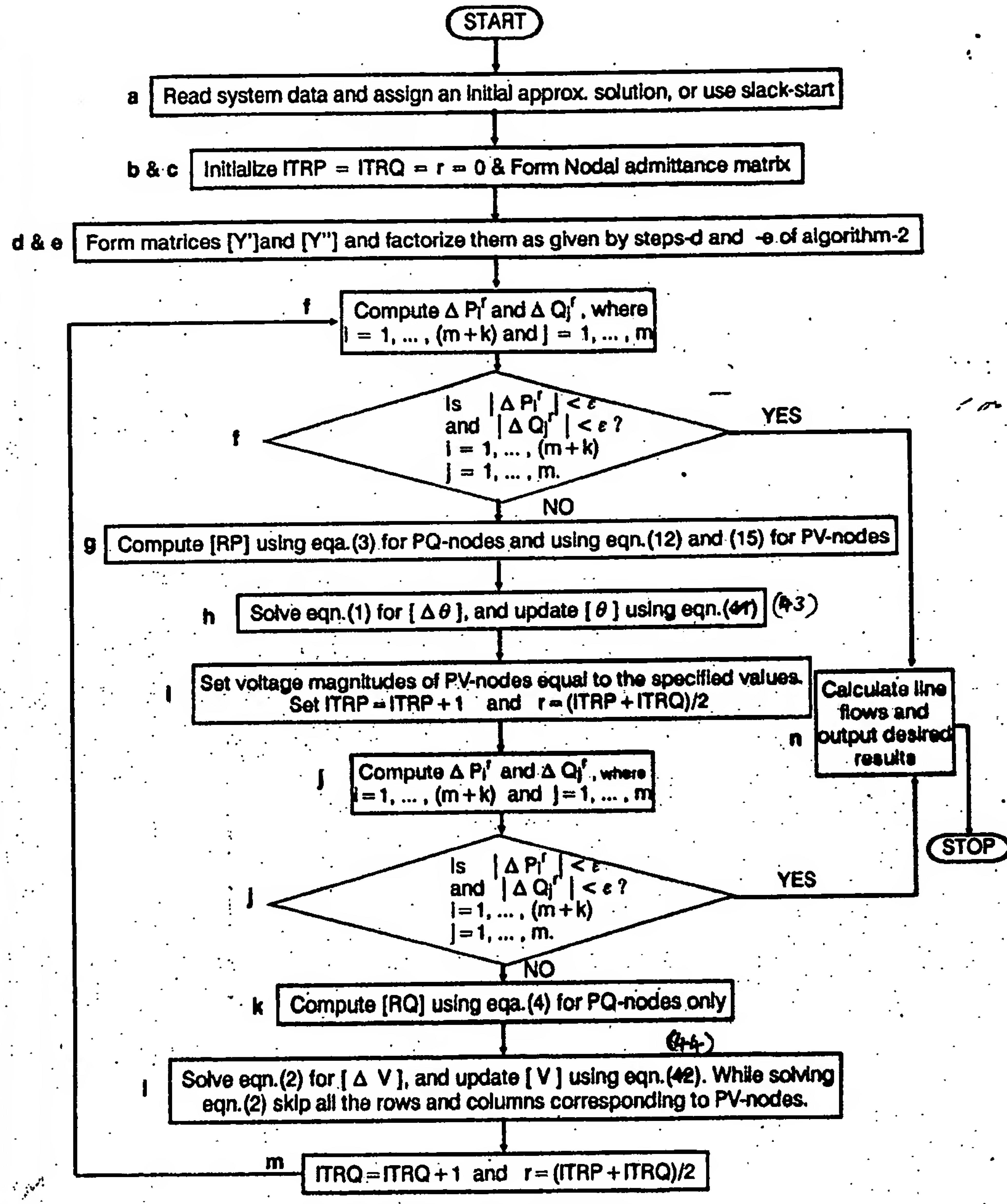

Fig. 2 Flow-chart of unadjusted load flow solution algorithm-2.
It is the same for FSDL, TFDLXB and TFDLBX methods. (flow-chart of invited methods)

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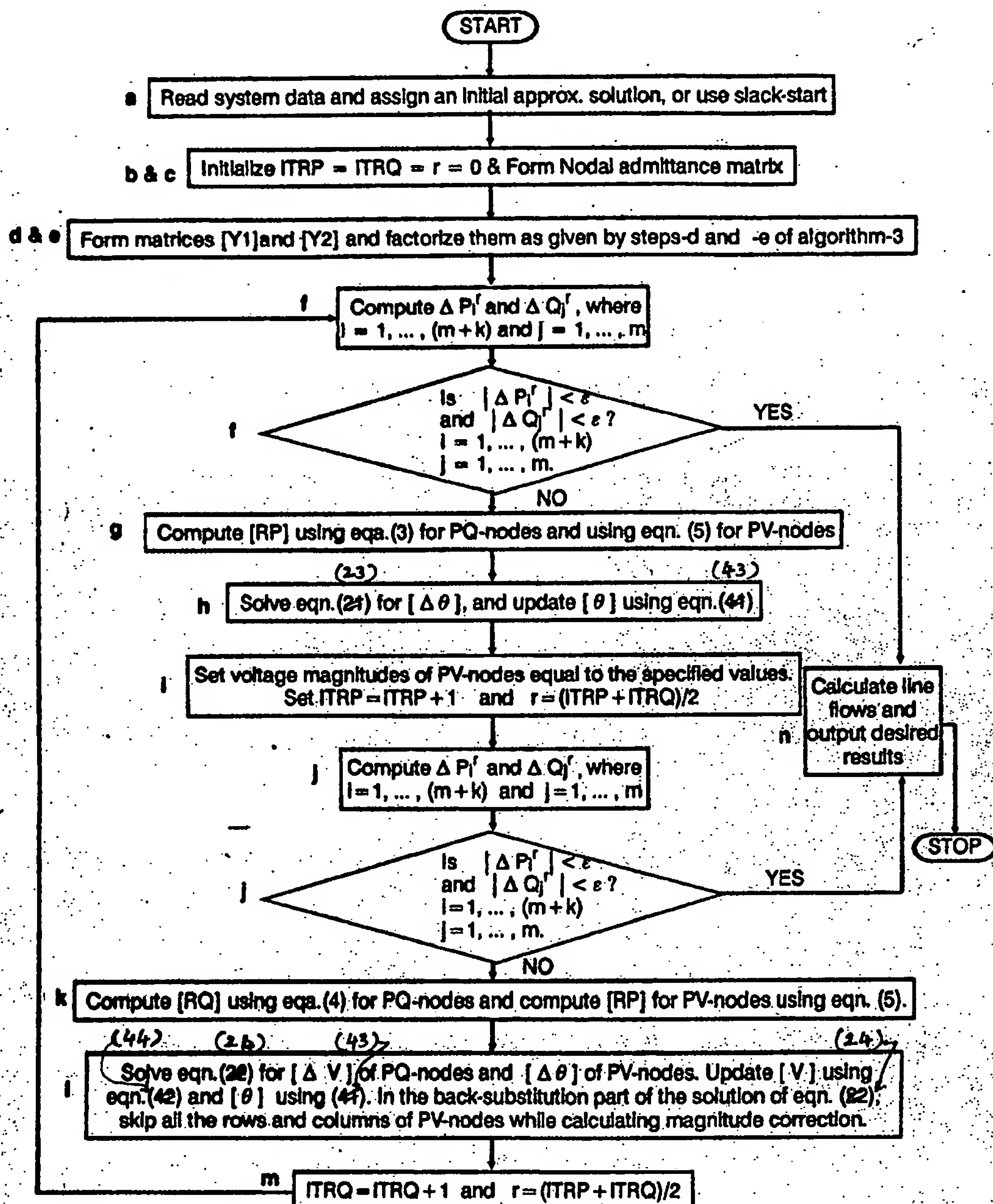

Fig. 3 Flow-chart of unadjusted load flow solution algorithm-3. It is the same for NFSDL, NTFDLXB and NTFDLBX methods. (flow-chart of invented methods)

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DERWENT-ACC-NO: 1995-240975
DERWENT-WEEK: 199532

TITLE: Super decoupled method for steady state loadflow analysis of power system using computer algorithms to process raw data

INVENTOR: PATEL S B

PATENT-ASSIGNEE: PATEL S B[PATEI]

PRIORITY-DATA: 1993CA-2107388 (November 9, 1993)

PATENT-FAMILY:

PUB-NO	PUB-DATE	LANGUAGE
CA 2107388 A	May 10, 1995	EN

APPLICATION-DATA:

PUB-NO	APPL-DESCRIPTOR	APPL-NO	APPL-DATE
CA 2107388A	N/A	1993CA-2107388	November 9, 1993

INT-CL-CURRENT:

TYPE	IPC DATE
CIPS	H04N5/30 20060101

ABSTRACTED-PUB-NO: CA 2107388 A

BASIC-ABSTRACT:

The super decoupled loadflow methods include FSDL, TFDLXB and TFDLBX, both in polar and cartesian co-ordinate forms, their novel versions and all possible hybrid combinations. The gain matrices of the six methods are defined. The rotation angle (?p) is restricted to -36?.

A real power mismatch at PV-nodes is modulated to ensure that the coefficient/gain matrix is symmetrical. It can be used in all possible computer algorithms. Angle corrections are computed and updated for PV-nodes along with voltage magnitude corrections while solving certain equations within the algorithms. The rows and columns corresp. to PV-nodes may be skipped for calculation of voltage magnitude corrections of PQ-nodes.

USE/ADVANTAGE - Steady state analysis of electrical power network. Reliable operation. Simplified algorithms involve fewer calculations per iterations.

CHOSEN-DRAWING: Dwg.2/3

TITLE-TERMS: SUPER DECOUPLE METHOD STEADY STATE ANALYSE POWER SYSTEM COMPUTER ALGORITHM PROCESS RAW DATA

DERWENT-CLASS: T01 X12

EPI-CODES: T01-J08; T01-S; X12-H05;

SECONDARY-ACC-NO:

Non-CPI Secondary Accession Numbers: 1995-187940